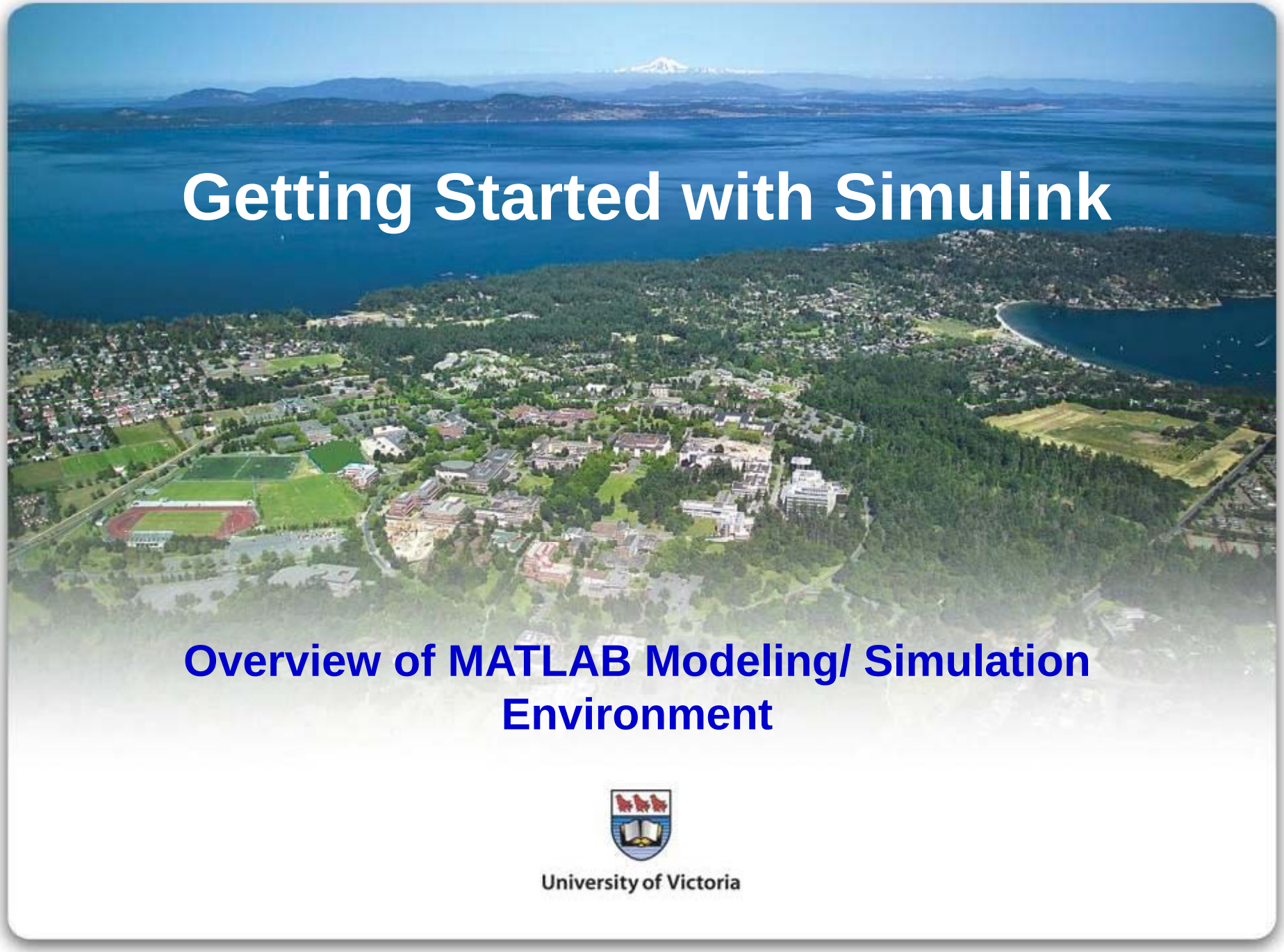


Getting Started with Simulink

Overview of MATLAB Modeling/ Simulation Environment

University of Victoria

MATLAB/Simulink Applications

- Mechanical System
- Automotive
- Controls
- Robotics
- Aerospace and Defense
- Communications
- Electronics and Signal Processing
- Medical Instrumentation

Model-Based Design

- Faster, more cost-effective development of dynamic systems (e.g. control systems, vehicles, etc.)
- A system model is at the center of the development process, from requirements development, through design, implementation, and testing.
- Model - an executable specification (MATLAB codes, or a block diagram and specified parameters) that is continually refined (optimized) throughout the development.
- Simulation – test whether the model works correctly, and obtain results.
- Software and hardware implementation – automatic code generation

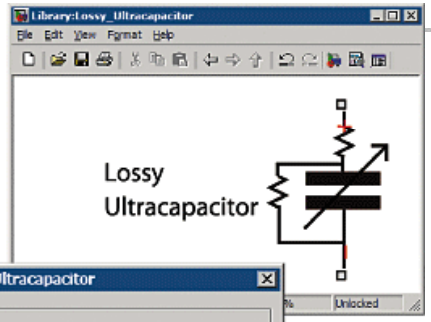
MATLAB Codes – Simulink Block & Block Parameters

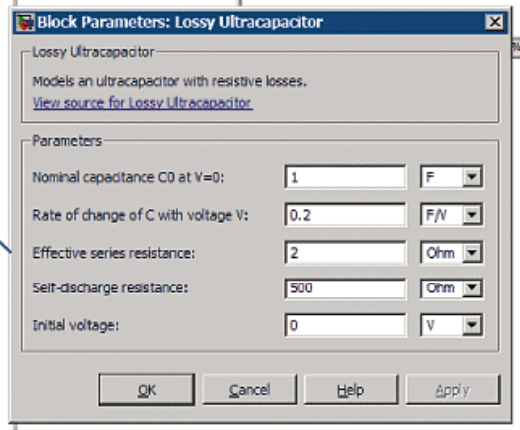
Editor - C:\Lossy_Capacitor.ssc

File Edit Text Go Tools Debug Desktop Window Help

```
component lossy_ultracapacitor
% Lossy Ultracapacitor
% Models an ultracapacitor with resistive losses.
  nodes
    p = foundation.electrical.electrical % +:top
    n = foundation.electrical.electrical; % -:bottom
  end
  parameters
    C0 = { 1, 'F' }; % Nominal capacitance C0 at V=0
    Cv = { 0.2, 'F/V'}; % Rate of change of C with voltage V
    R = {2, 'Ohm' }; % Effective series resistance
    Rd = {500, 'Ohm' }; % Self-discharge resistance
    V0 = { 0, 'V' }; % Initial voltage
  end
  variables
    i = { 0, 'A' }; % Current through variable
    v = { 0, 'V' }; % Voltage across variable
    vc = { 0, 'V' }; % Internal variable
  end
  function setup
    if R <= { 0, 'Ohm'}
      error( 'Resistance must be greater than zero' )
    end
    through( i, p.i, n.i ); % Through variable i
    across( v, p.v, n.v ); % Across variable v
    vc = V0;
  end
  equation
    i == (C0 + Cv*v)*vc.der + vc/Rd; % Equation 1
    v == vc + i*R; % Equation 2
  end
end
```

Simscape file Ln 24





$$i = (C_0 + C_v v)\frac{dv}{dt} + \frac{v}{r_d}$$

Modeling Process

On Paper:

1 Defining the System

2 Identifying System Components

3 Modeling the System with Equations

Using MATLAB/Simulink:

4 Building the Simulink Block Diagram

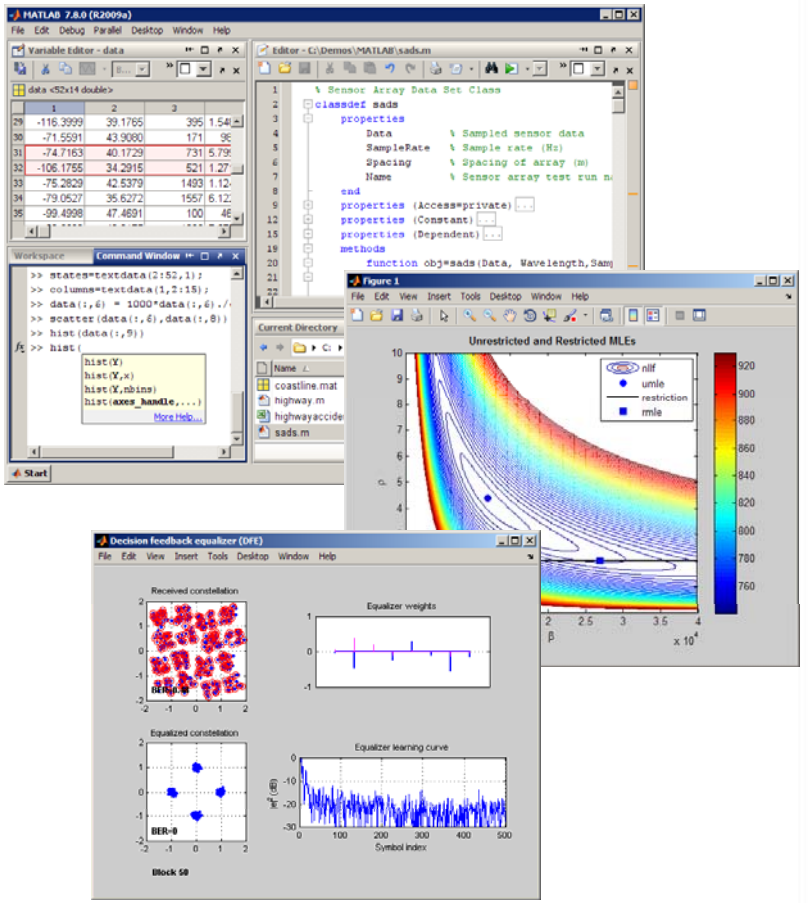
5 Running the Simulation

6 Validating the Simulation Results

MATLAB®

The leading environment for technical computing

- The *de facto* industry-standard, high-level programming language for algorithm development
- Numeric computation
- Data analysis and visualization
- Toolboxes for signal and image processing, statistics, optimization, symbolic math, and other areas
- Foundation of MathWorks products

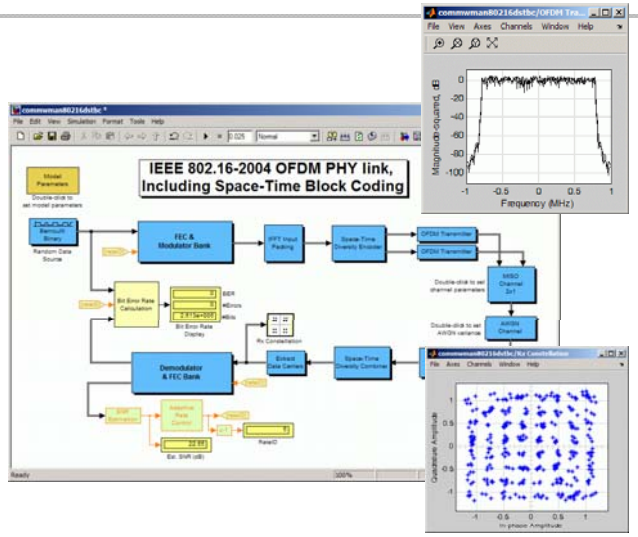


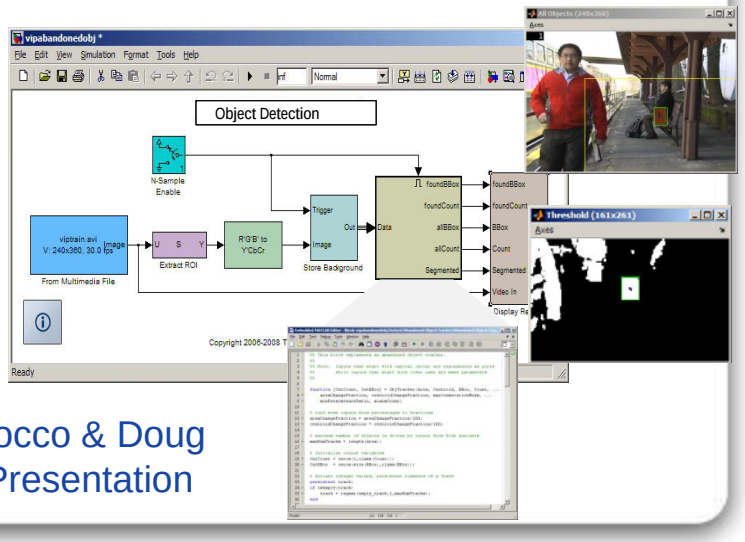
from Bryan Zocco & Doug Eastman's Presentation

SIMULINK®

The leading environment for system-level modeling, simulation, and verification of communications and electronic systems

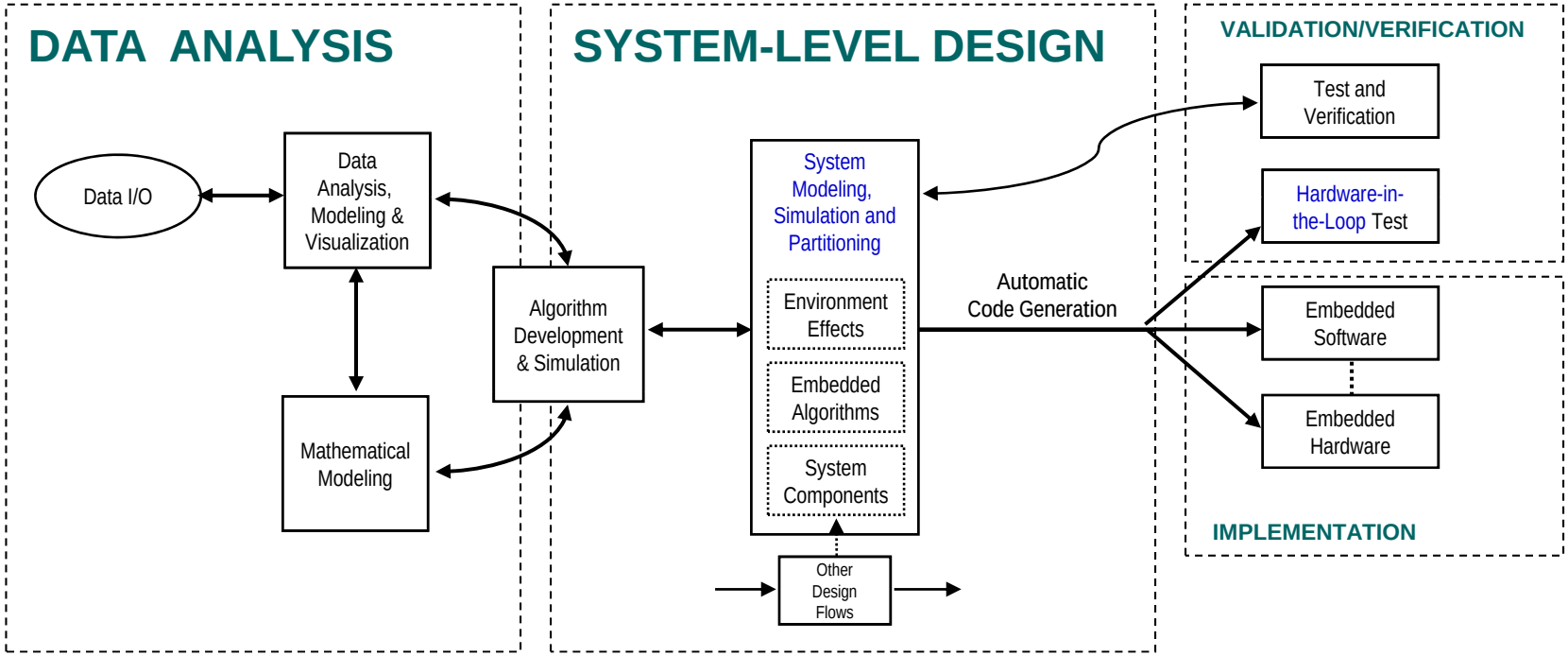
- Multidomain system-level design and verification
- Digital, analog, and mixed-signal simulation using discrete-time, continuous-time, state machine, and discrete event modeling
- Floating- and fixed-point algorithm development using MATLAB, Simulink blocks, or existing C code
- Blocksets for signal processing, video processing, communications, and RF
- Open architecture with links to third-party tools and development boards, and instrumentation
- C and HDL code generation for DSPs, embedded processors, and FPGAs





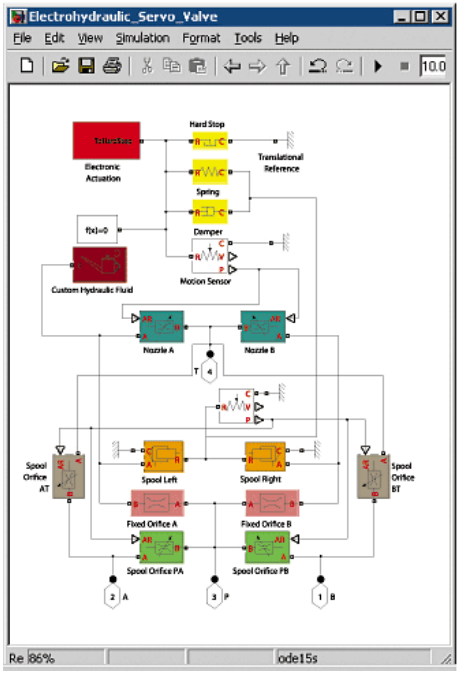
from Bryan Zocco & Doug Eastman's Presentation

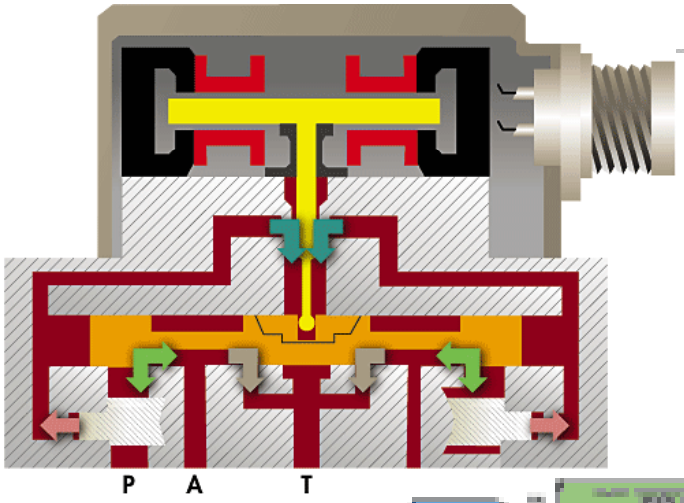
From Research to Development and Test

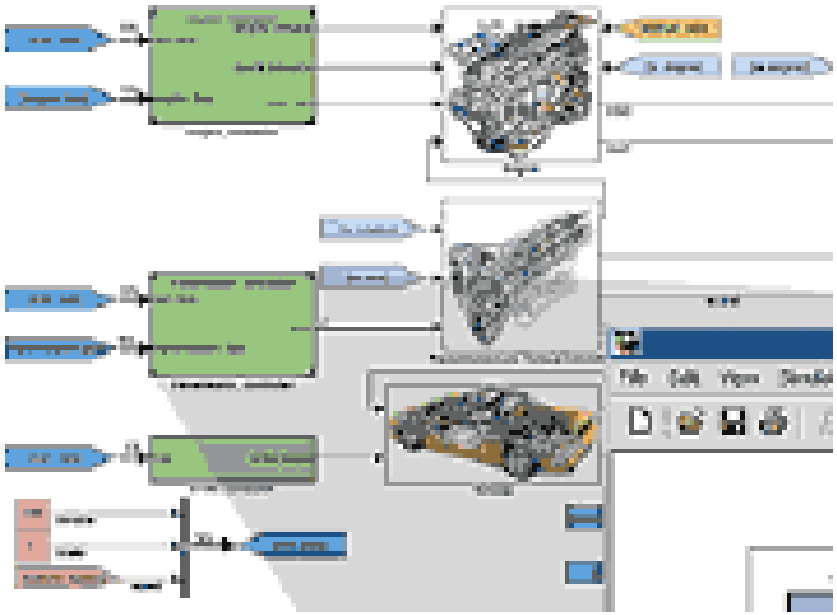


from Bryan Zocco & Doug Eastman's Presentation

Graphical Layout of Functional Modules

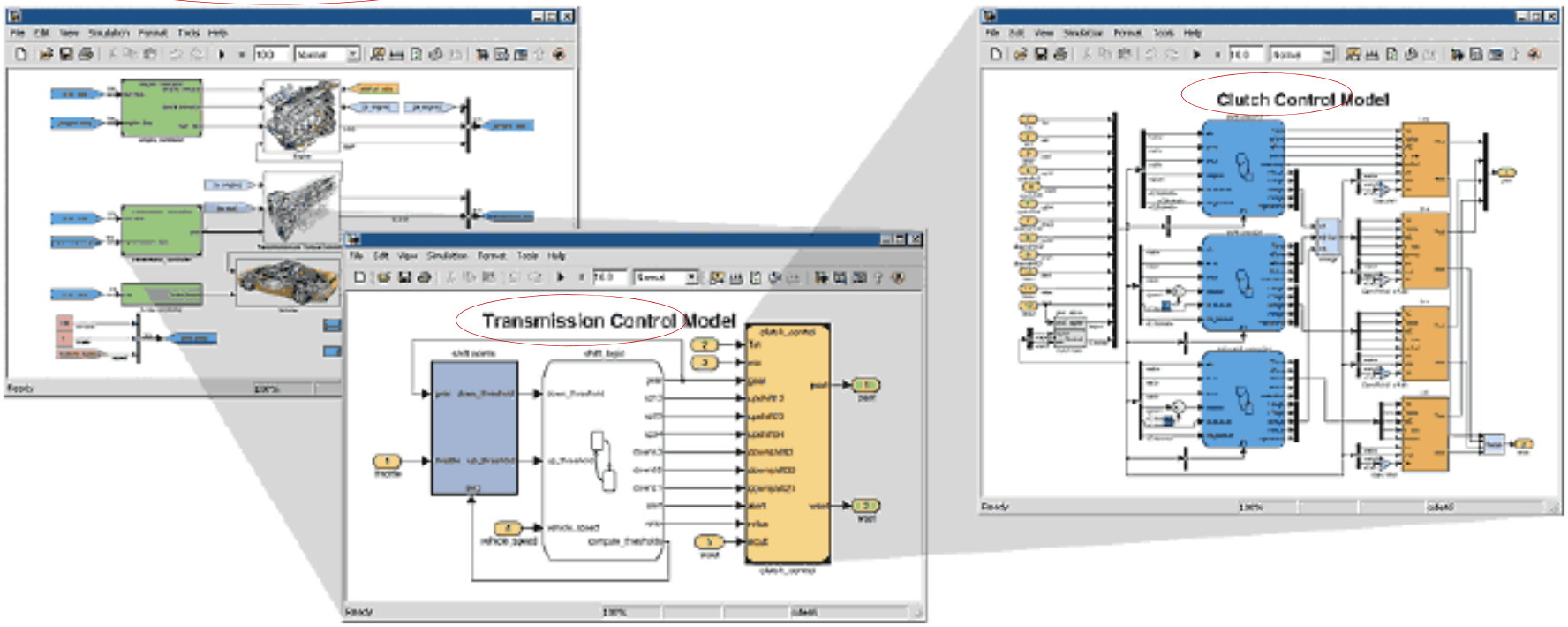




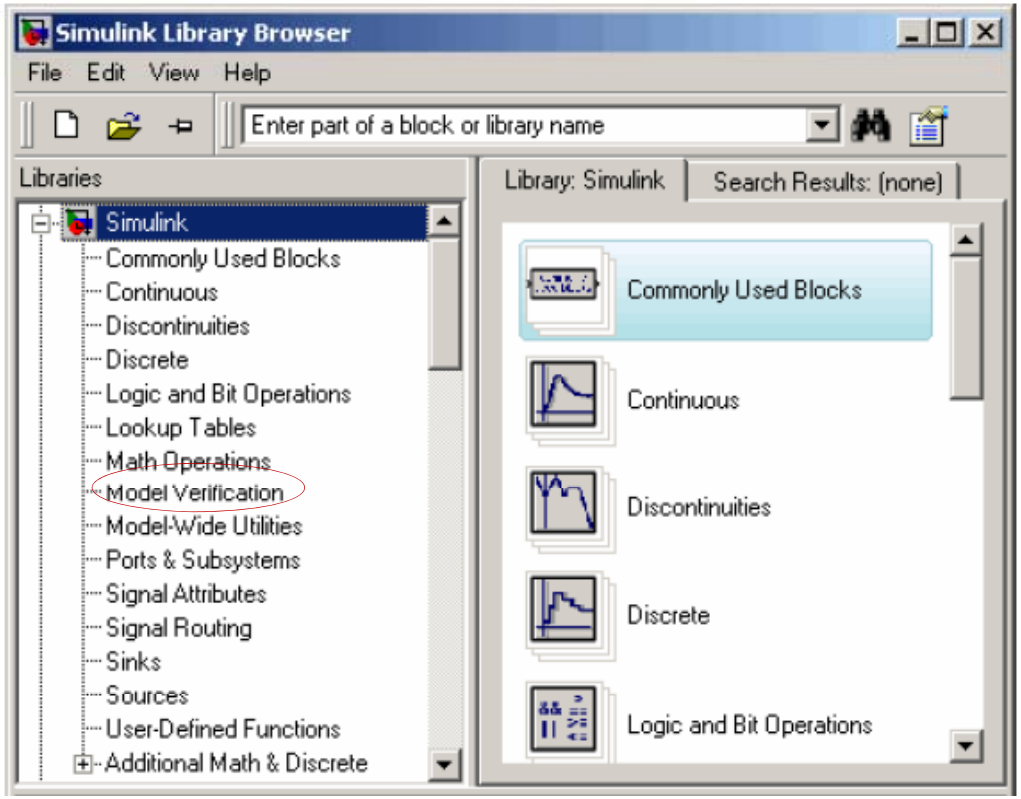


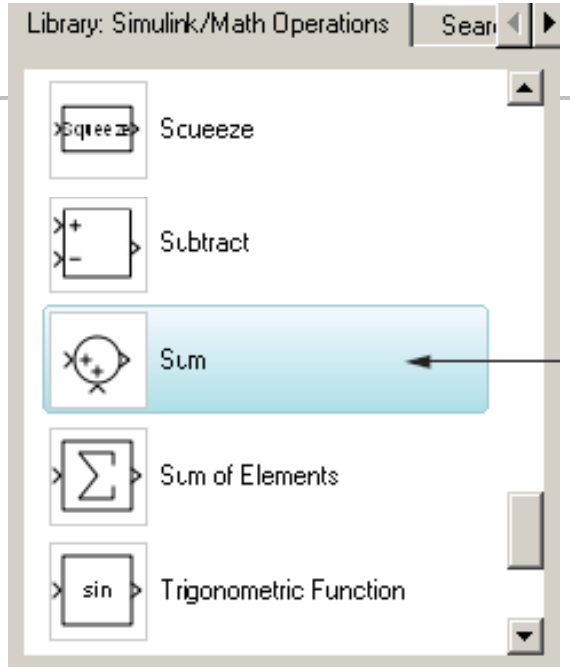
Complex System Model from Basic Building Blocks

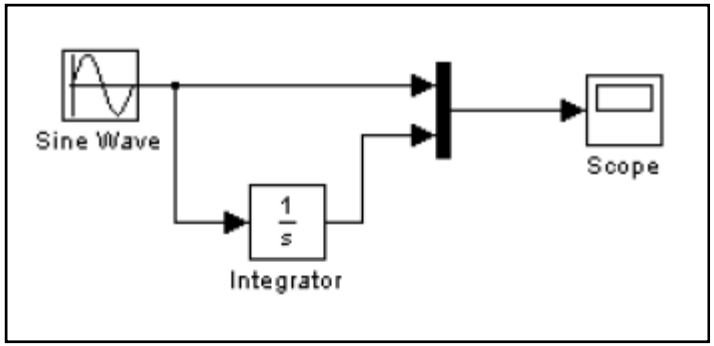
Vehicle and Control



Simulink Library (blocks)







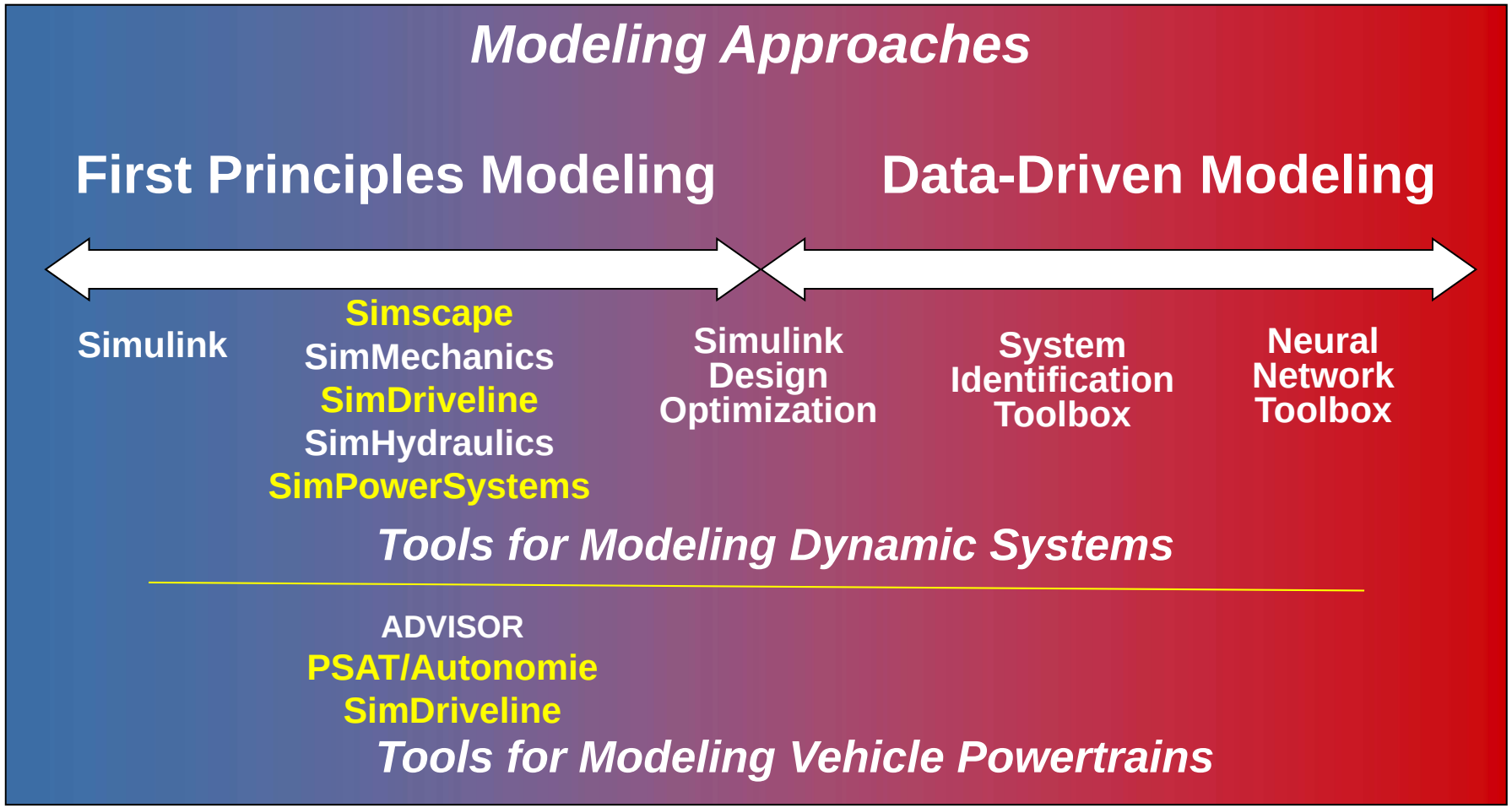
Block Library	Description
Commonly Used Blocks	Contains a group of the most commonly used blocks, such as the **Constant**, **In1**, **Out1**, **Scope**, and **Sum** blocks. Each of the blocks in this library are also included in other libraries.
Continuous	Contains blocks that model linear functions, such as the **Derivative** and **Integrator** blocks.
Discontinuities	Contains blocks with outputs that are discontinuous functions of their inputs, such as the **Saturation** block.
Discrete	Contains blocks that represent discrete time functions, such as the **Unit Delay** block.
Logic and Bit Operations	Contains blocks that perform logic or bit operations, such as the **Logical Operator** and **Relational Operator** blocks.
Sinks	Contains blocks that display or export output, such as the **Out1** and **Scope** blocks.
Sources	Contains blocks that generate or import system inputs, such as the **Constant**, **In1**, and **Sine Wave** blocks.

Block Library	Description
LookUp Tables	Contains blocks that use lookup tables to determine their outputs from their inputs, such as the **Cosine** and **Sine** blocks.
Math Operations	Contains blocks that perform mathematical and logical functions, such as the **Gain**, **Product**, and **Sum** blocks.
Model Verification	Contains blocks that enable you to create self-validating models, such as the **Check Input Resolution** block.
Model-Wide Utilities	Contains blocks that provide information about the model, such as the **Model Info** block.
Ports & Subsystems	Contains blocks that allow you to create subsystems, such as the **In1**, **Out1**, and **Subsystem** blocks.
Signal Attributes	Contains blocks that modify the attributes of signals, such as the **Data Type Conversion** block.
Signal Routing	Contains blocks that route signals from one point in a block diagram to another, such as the **Mux** and **Switch** blocks.
User-Defined Functions	Contains blocks that allow you to define custom functions, such as the **Embedded MATLAB™ Function** block.
Additional Math & Discrete	Contains two additional libraries for mathematical and discrete function blocks.

Key Multiphysics Modeling Toolbox

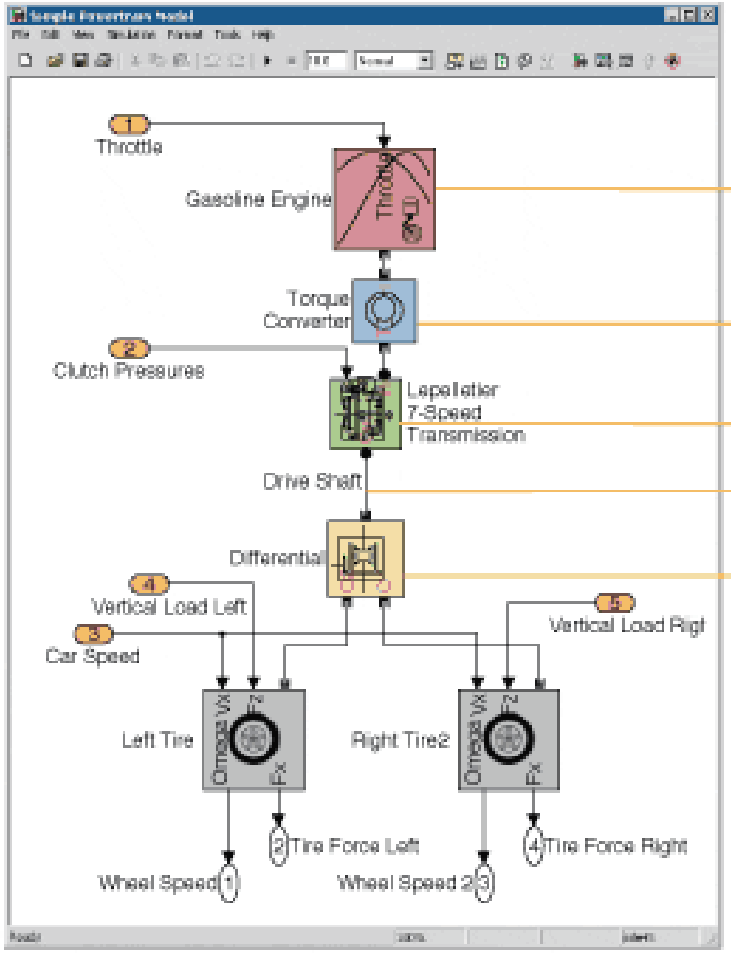
Stateflow™	Design and simulate state machines and control logic.
SimMechanics™	Model and simulate mechanical systems.
SimPowerSystems™	Model and simulate electrical power systems.
Simulink® Control Design™	Design and analyze control systems in Simulink.
SimScape™	Provides expanded capabilities for modeling physical systems (mechanical, electrical, hydraulic, and other physical domains as physical networks)
SimDriveline™	Modeling and simulating the mechanics of driveline (drivetrain) systems

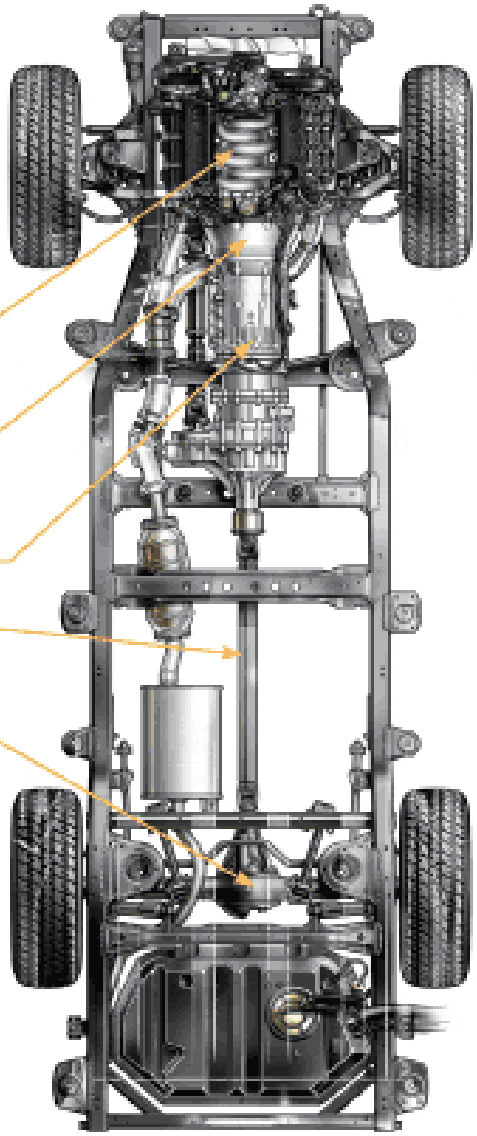
Modeling Dynamic Systems in Simulink



Modified from Bryan Zocco & Doug Eastman's Presentation

SimDriveline™ Model





Simulink Online Help

- ***Simulink Getting Started Guide***
- ***Simulink User's Guide***
- ***Simulink Reference***
- ***Writing S-Functions***
- ***Simulink Release Notes***
- ***Other Posted References***
- Homework: build the Simulink models following the model building examples

Getting started with Simulink

An introductory tutorial

ES205 Analysis and Design of Engineering Systems
Rose-Hulman Institute of Technology

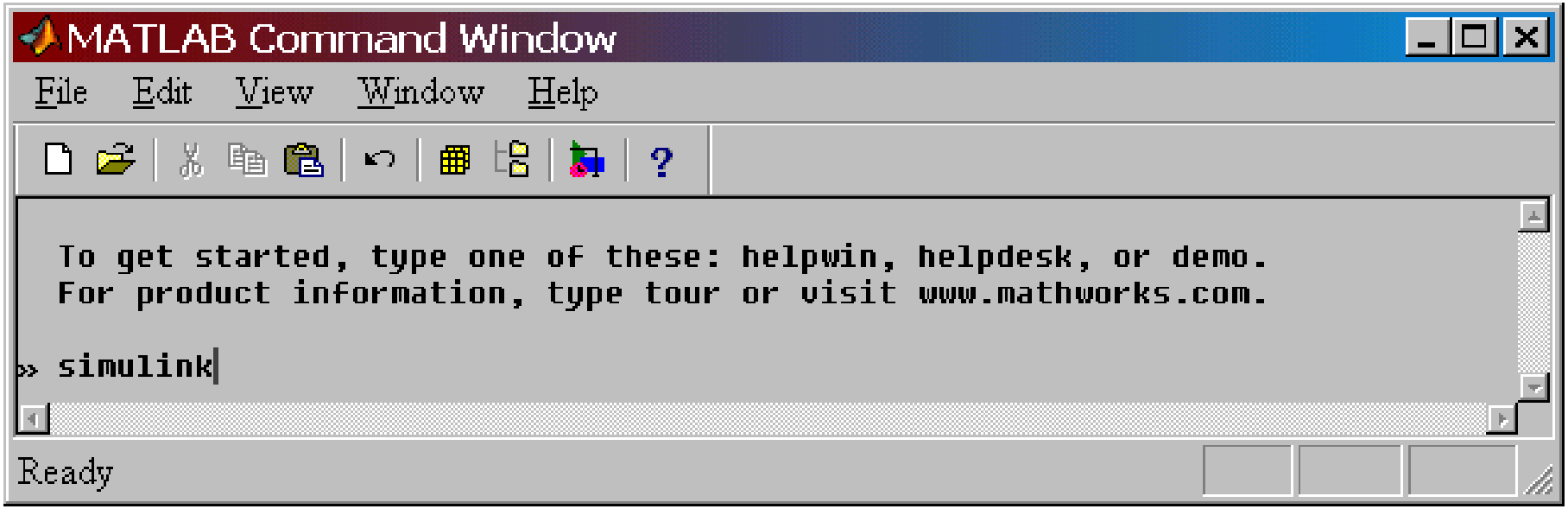
© R. Layton 2001

Launch Simulink

In the MATLAB command window,

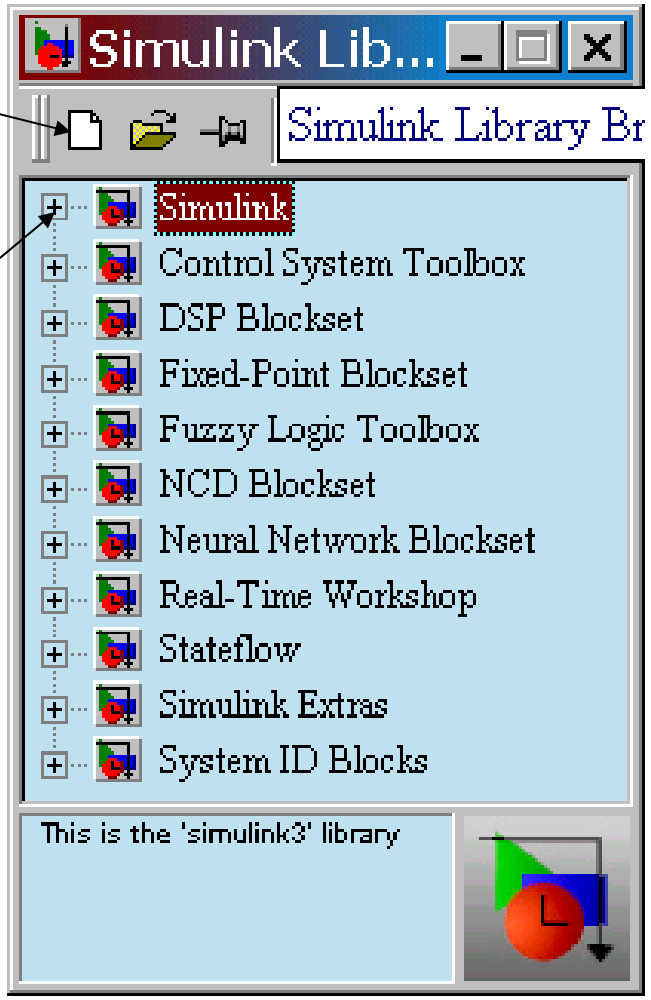
at the >> prompt, type **`simulink`**

and press ↵ Enter


MATLAB Command Window
File Edit View Window Help
To get started, type one of these: helpwin, helpdesk, or demo.
For product information, type tour or visit www.mathworks.com.
>> simulink
Ready

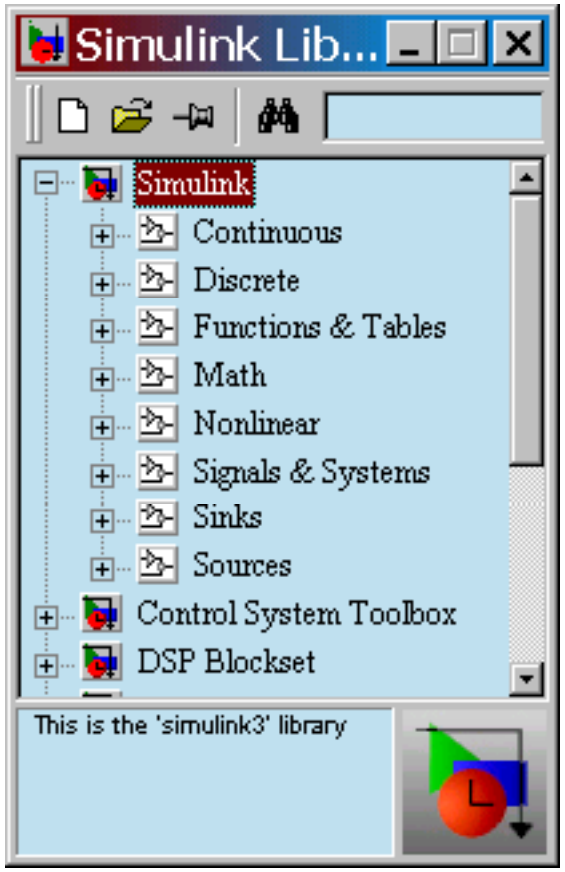
Create a new model

- Click the new-model icon in the upper left corner to start a new Simulink file
- Select the Simulink icon to obtain elements of the model

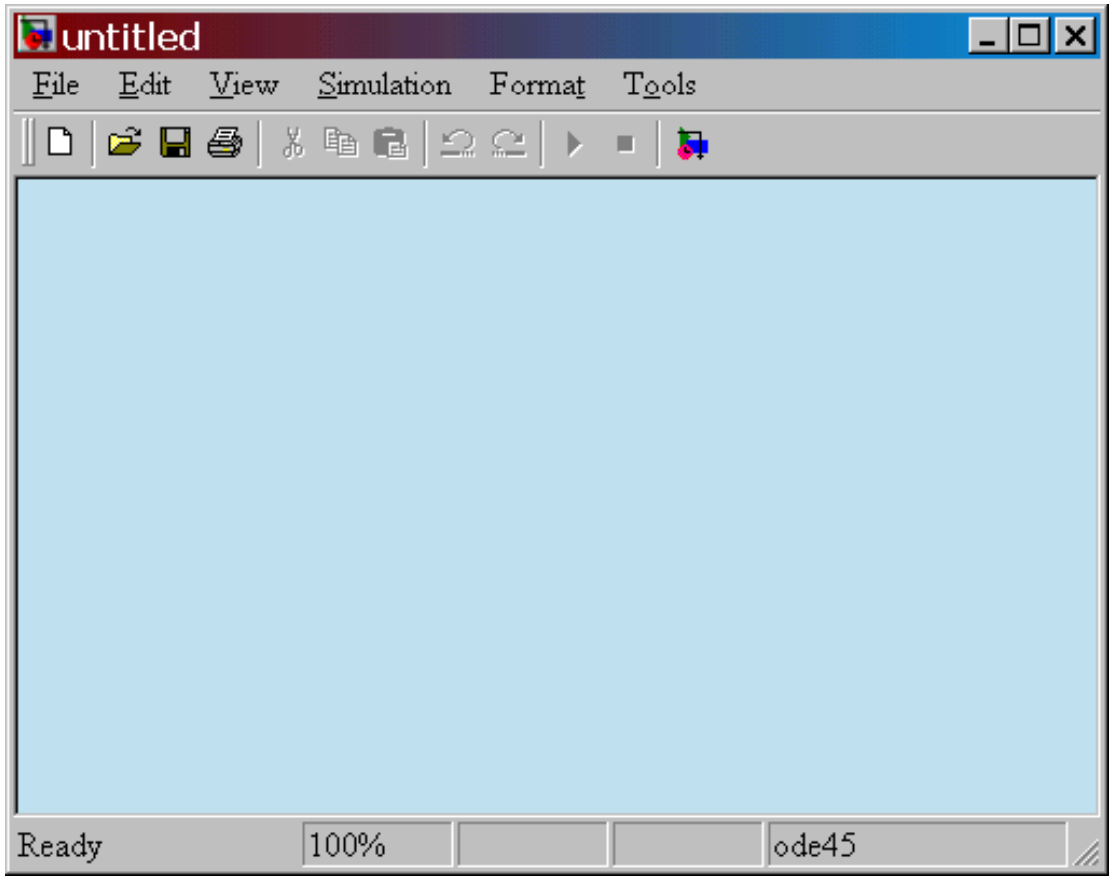


Your workspace

Library of elements

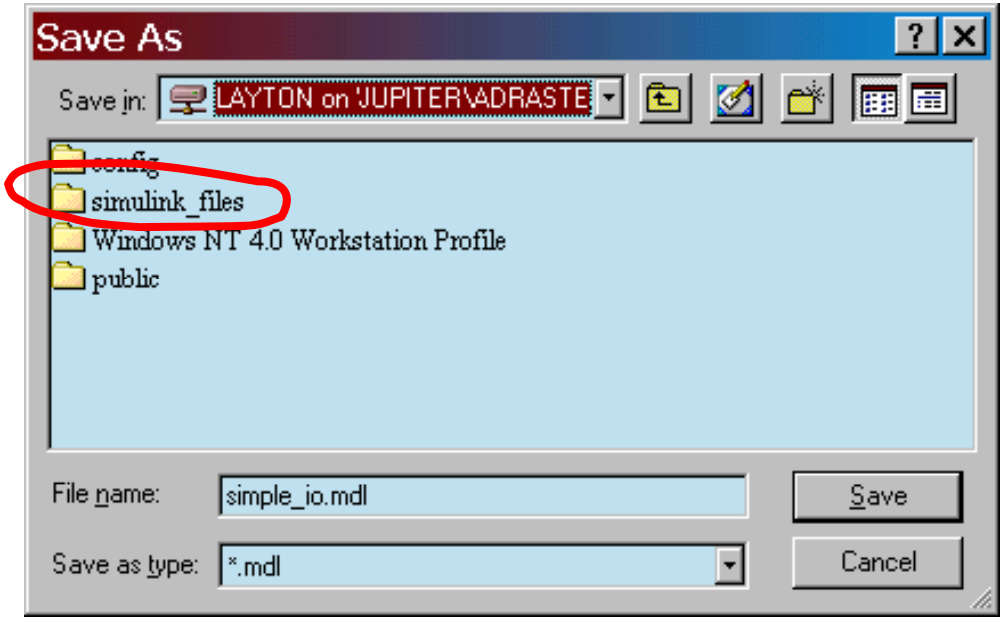


Model is created in this window



Save your model

- You might create a new folder, like the one shown below, called *simulink_files*
- Use the .mdl suffix when saving



Example 1: a simple model

- Build a Simulink model that solves the differential equation

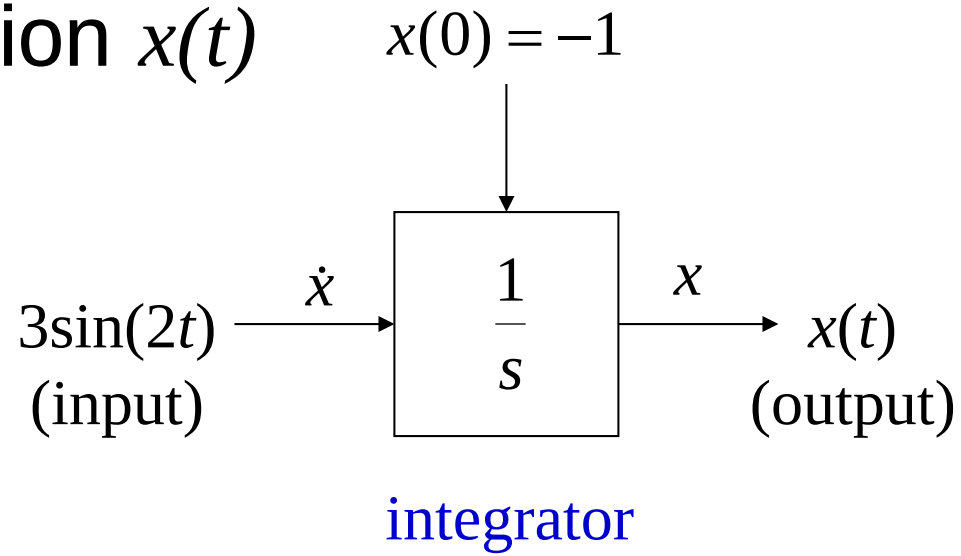
$$\dot{x} = 3\sin(2t)$$

- Initial condition $x(0) = -1.$
- First, sketch a simulation diagram of this mathematical model (equation)

(3 min.)

Simulation diagram

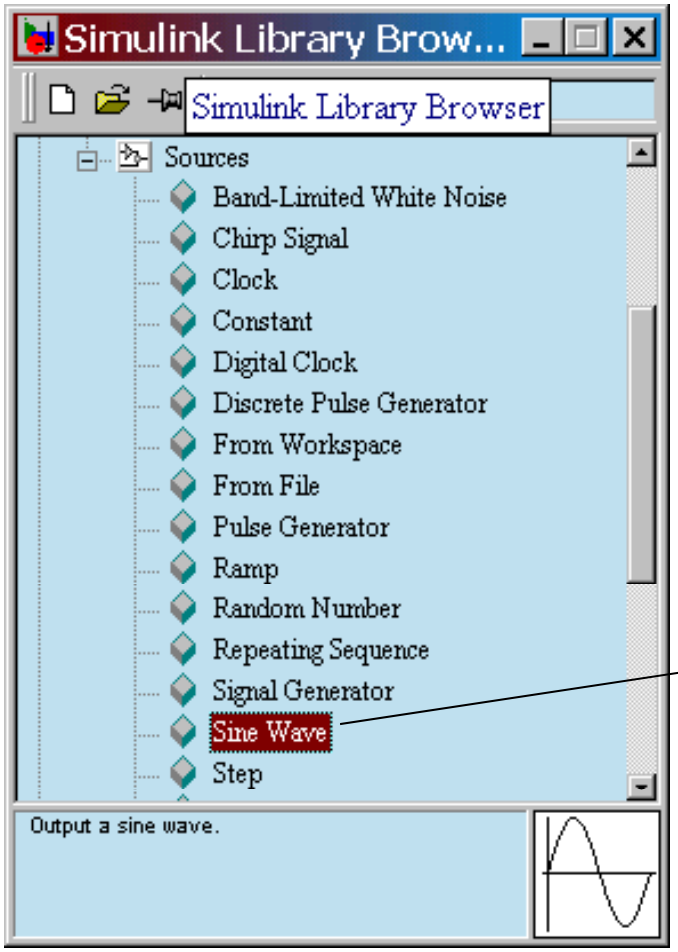
- Input is the forcing function $3\sin(2t)$
- Output is the solution of the differential equation $x(t)$



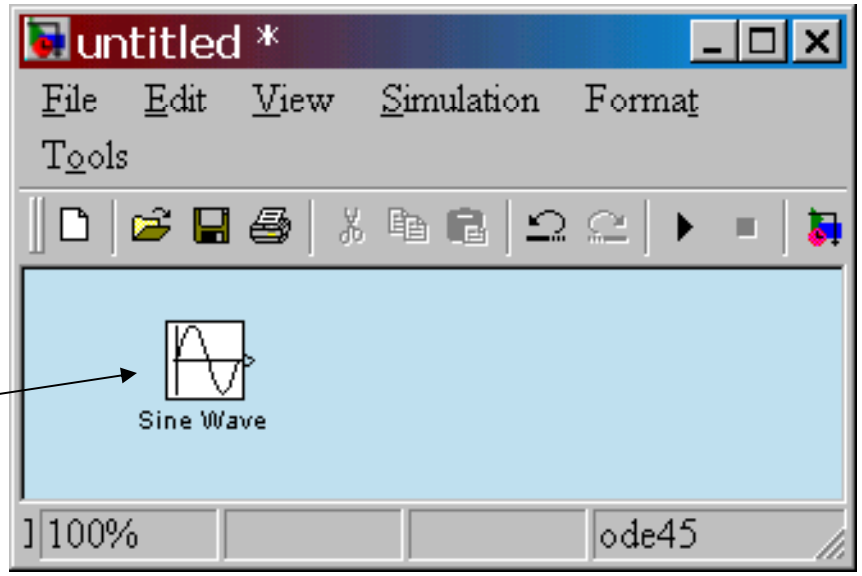
integrator

- Now build this model in Simulink

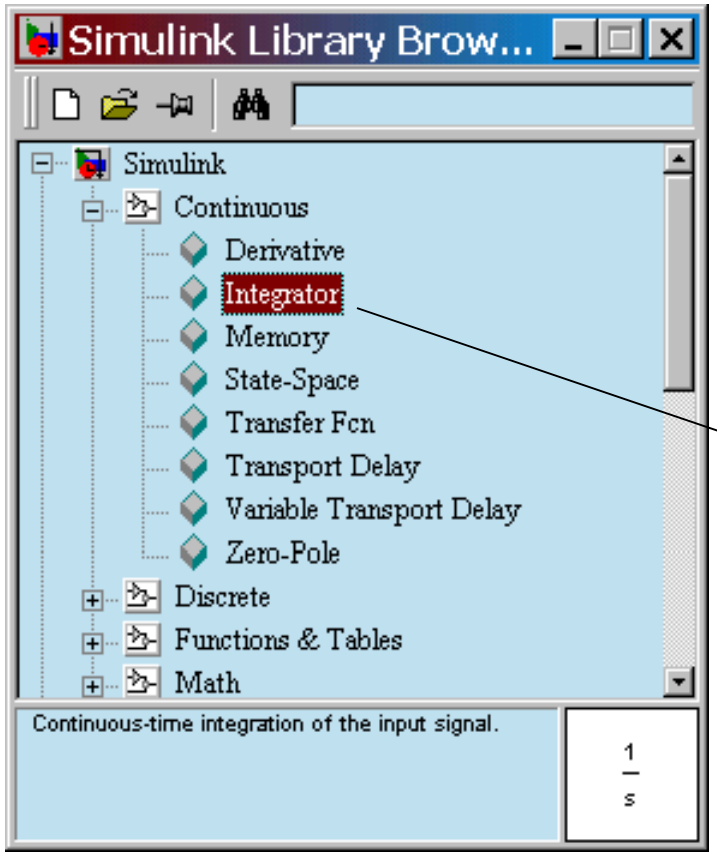
Select an input block



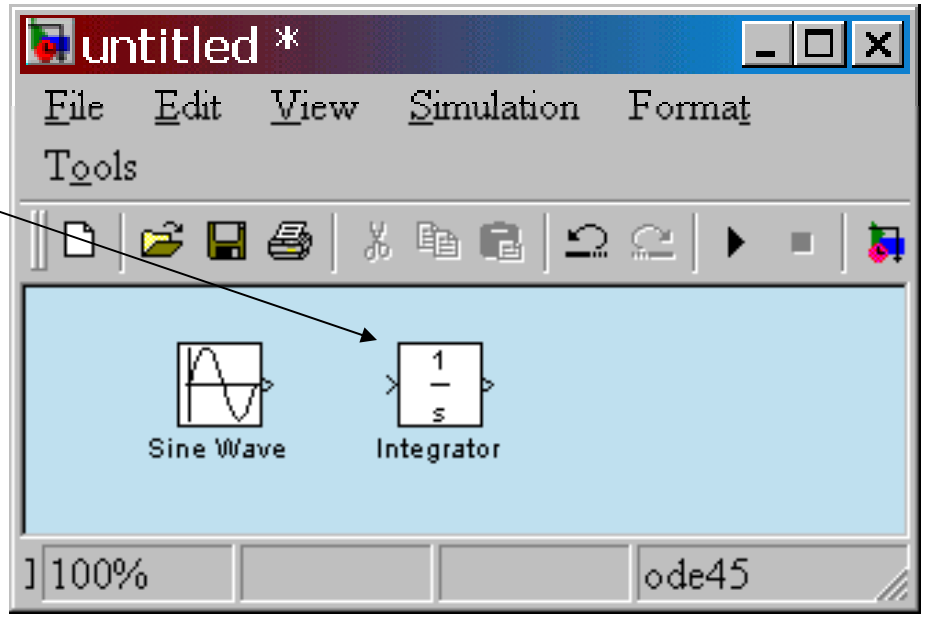
Drag a *Sine Wave* block from the *Sources* library to the model window



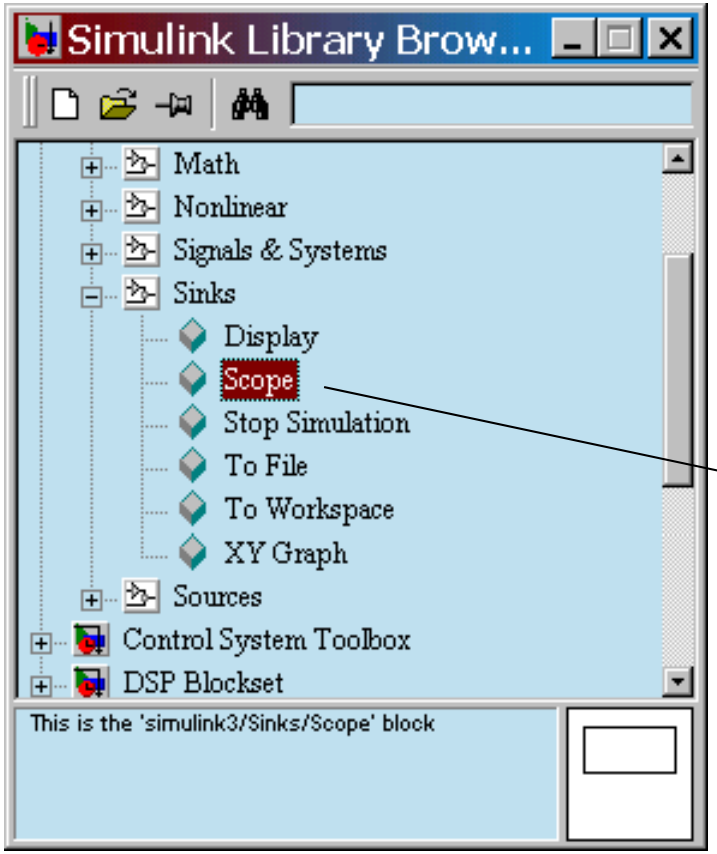
Select an operator block



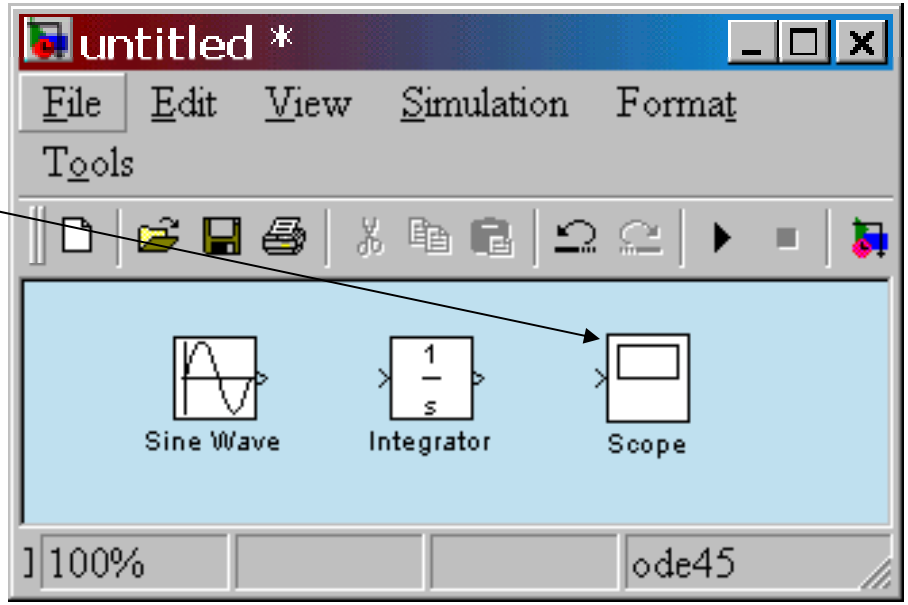
Drag an *Integrator* block from the *Continuous* library to the model window



Select an output block

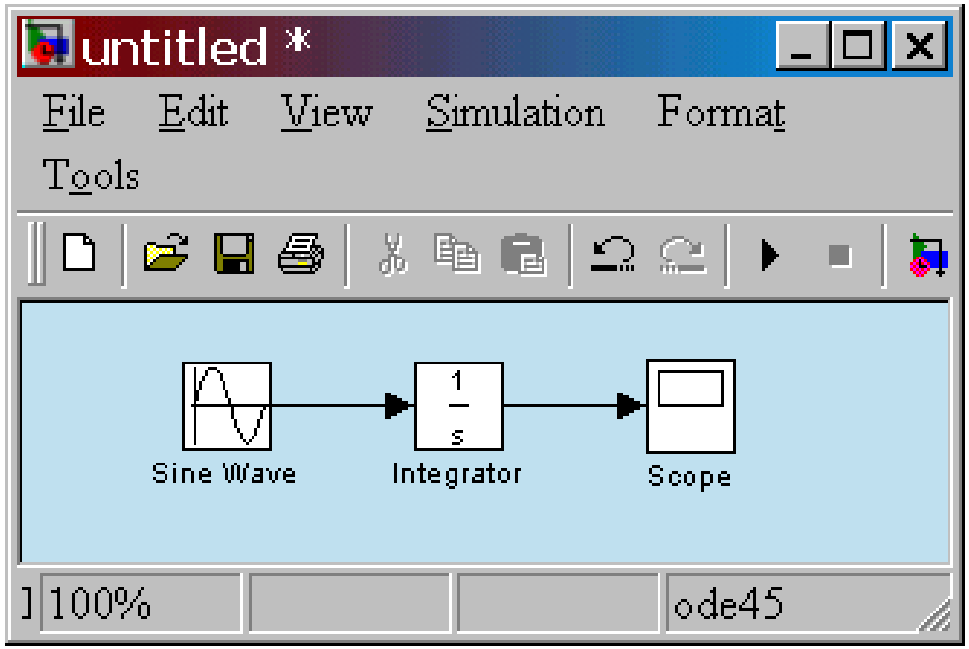


Drag a *Scope* block from the *Sinks* library to the model window



Connect blocks with signals

- Place your cursor on the output port (>) of the *Sine Wave* block
- Drag from the *Sine Wave* **output** to the *Integrator* **input**
- Drag from the *Integrator* **output** to the *Scope* **input**

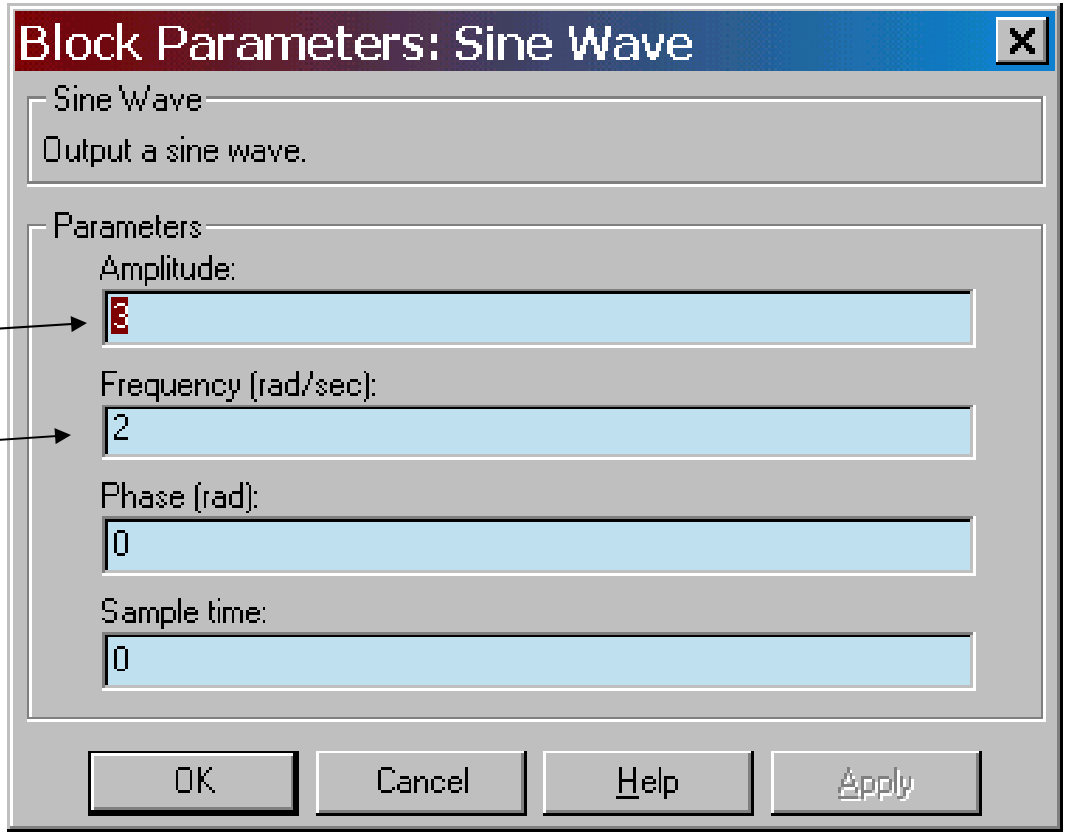


Arrows indicate the direction of the signal flow.

Select simulation parameters

Double-click on the *Sine Wave* block to set amplitude = 3 and freq = 2.

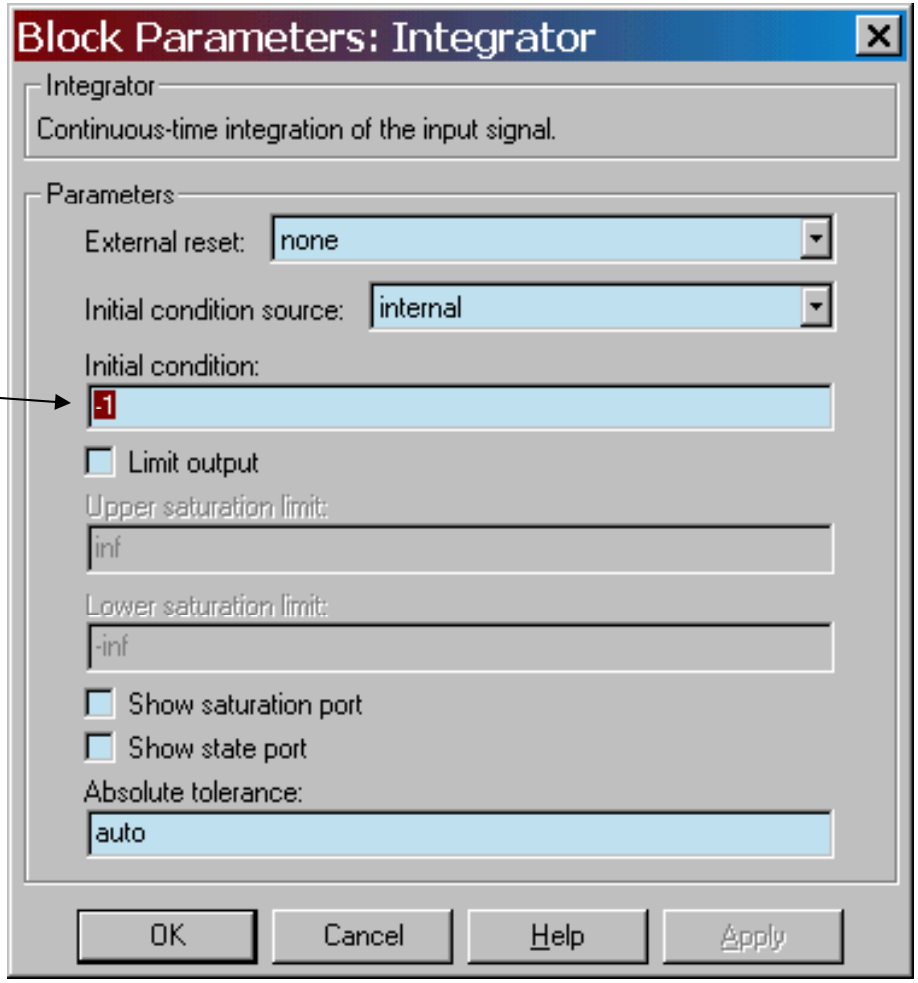
This produces the desired input of $3\sin(2t)$



Select simulation parameters

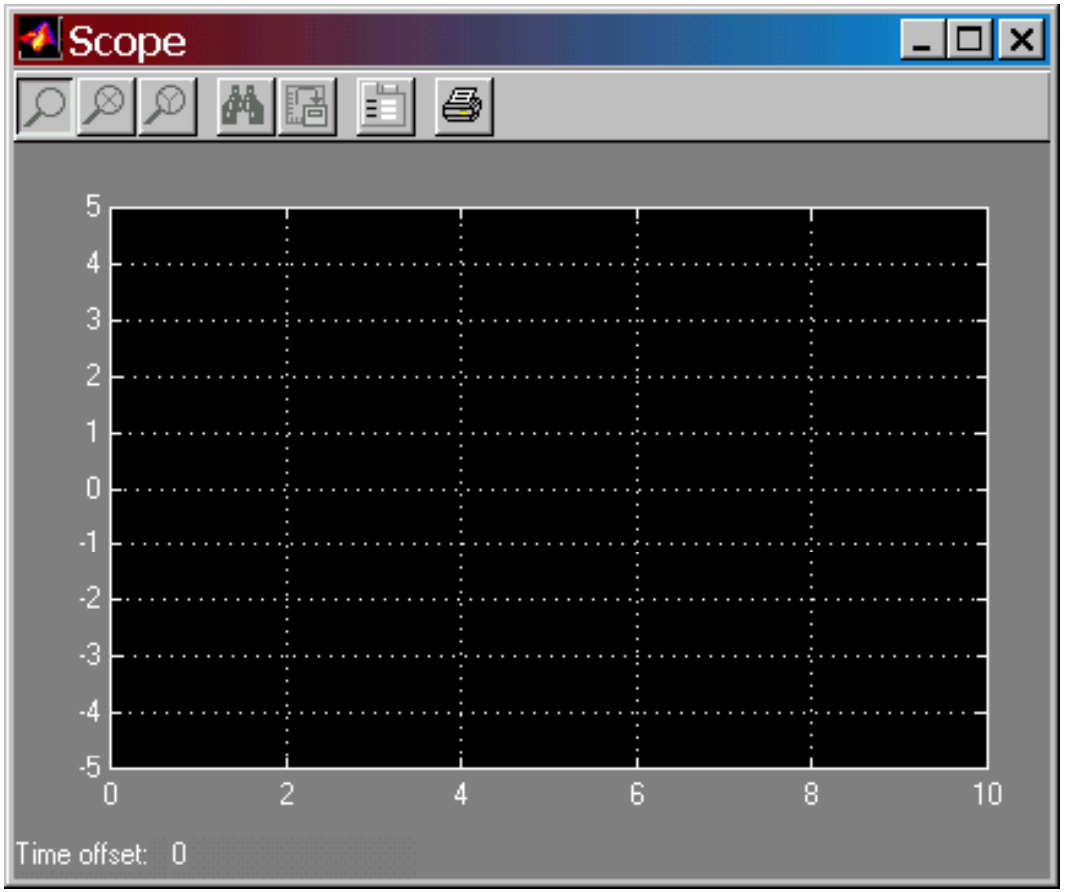
Double-click on the *Integrator* block to set initial condition = -1.

This sets our IC $x(0) = -1$.



Select simulation parameters

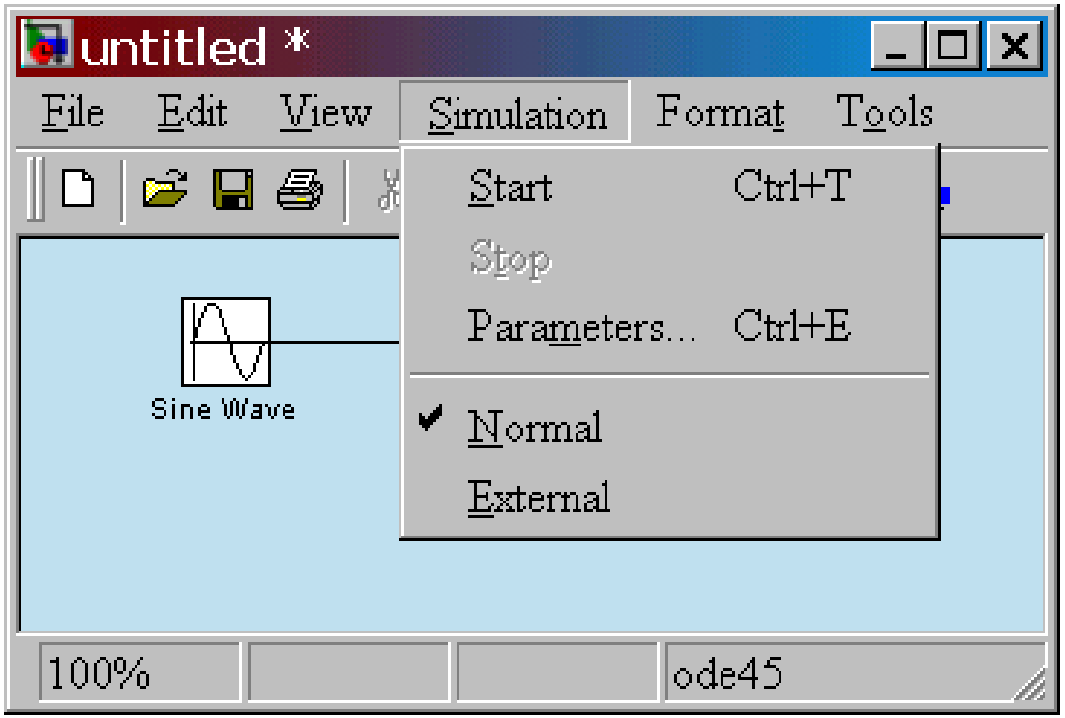
Double-click on the *Scope* to view the simulation results



Run the simulation

In the model window, from the *Simulation* pull-down menu, select *Start*

View the output $x(t)$ in the *Scope* window.



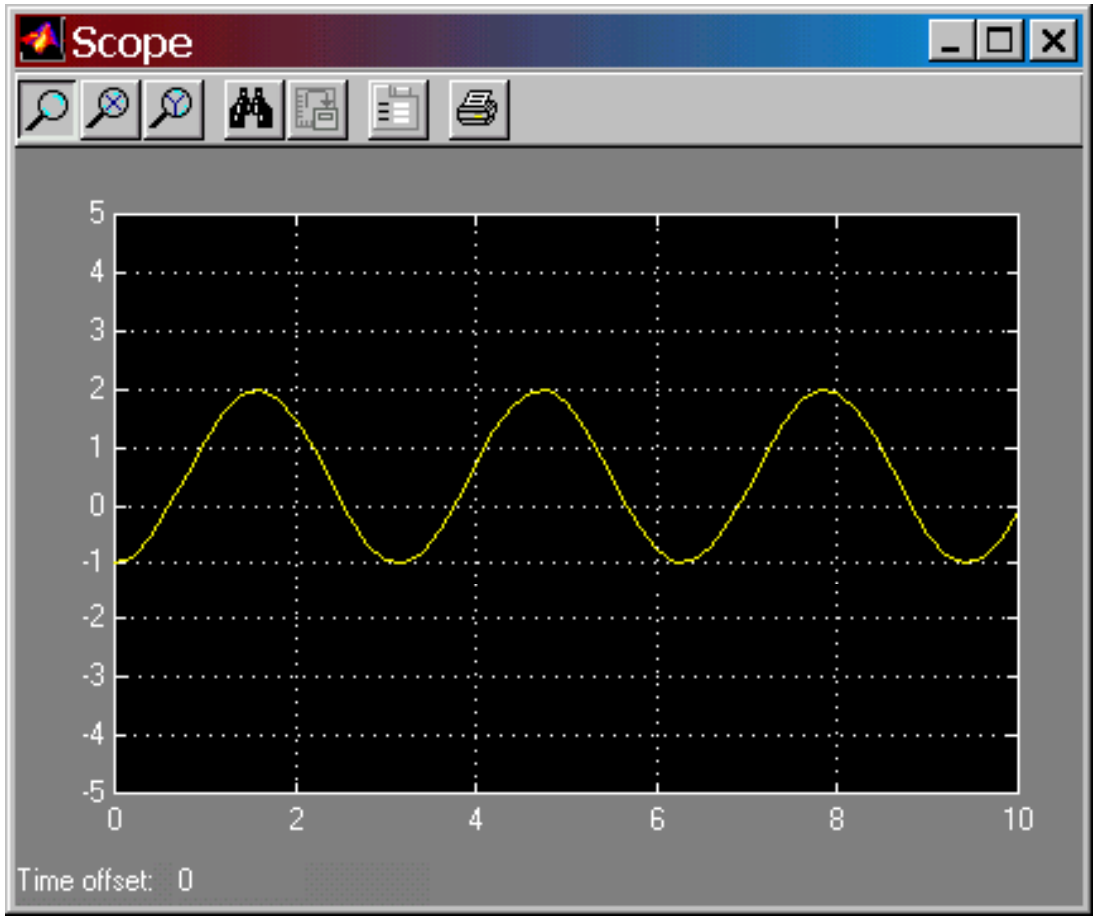
Simulation results

To verify that this plot represents the solution to the problem, solve the equation analytically.

The analytical result,

$$x(t) = \frac{1}{2} - \frac{3}{2}\cos(2t)$$

matches the plot (the simulation result) exactly.



Example 2

- Build a Simulink model that solves the following differential equation (ODE)
  - 2nd-order mass-spring-damper system
  - zero ICs
  - input *f(t)* is a step with magnitude 3
  - parameters: $m = 0.25$, $c = 0.5$, $k = 1$

$$m\ddot{x} + c\dot{x} + kx = f(t)$$

Create the simulation diagram

- On the following slides:
  - The simulation diagram for solving the ODE is created step by step.
  - After each step, elements are added to the Simulink model.
- Optional exercise: first, sketch the complete diagram (5 min.)

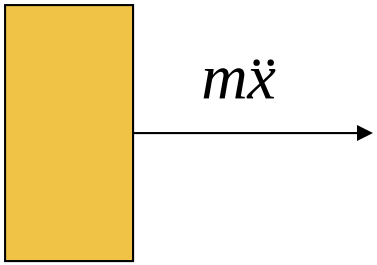
$$m\ddot{x} + c\dot{x} + kx = f(t)$$

(continue)

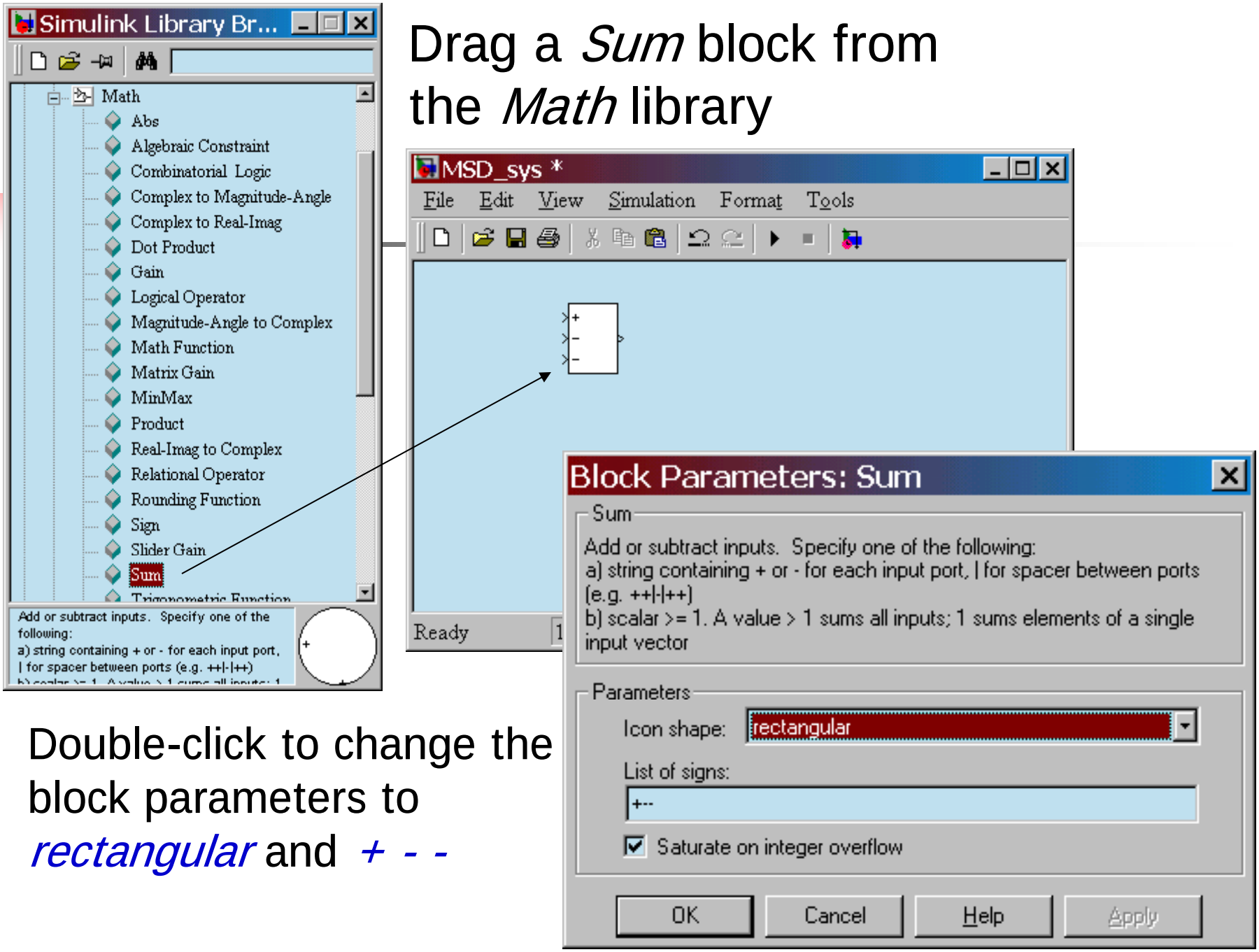
- First, solve for the term with highest-order derivative

$$m\ddot{x} = f(t) - c\dot{x} - kx$$

- Make the left-hand side of this equation the output of a summing block



summing block

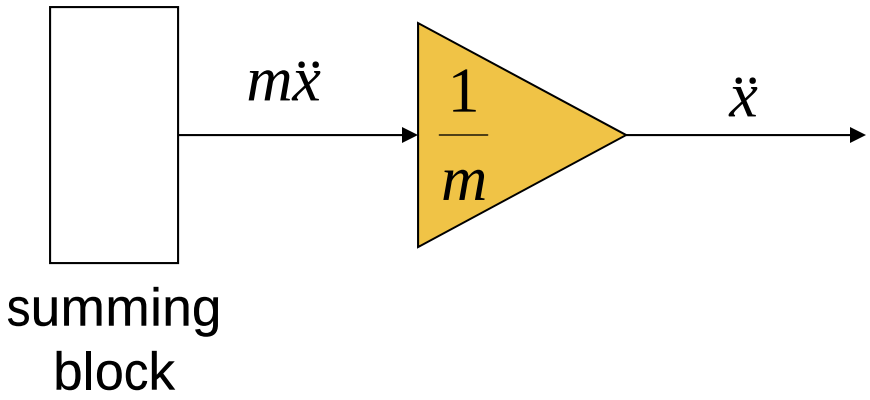


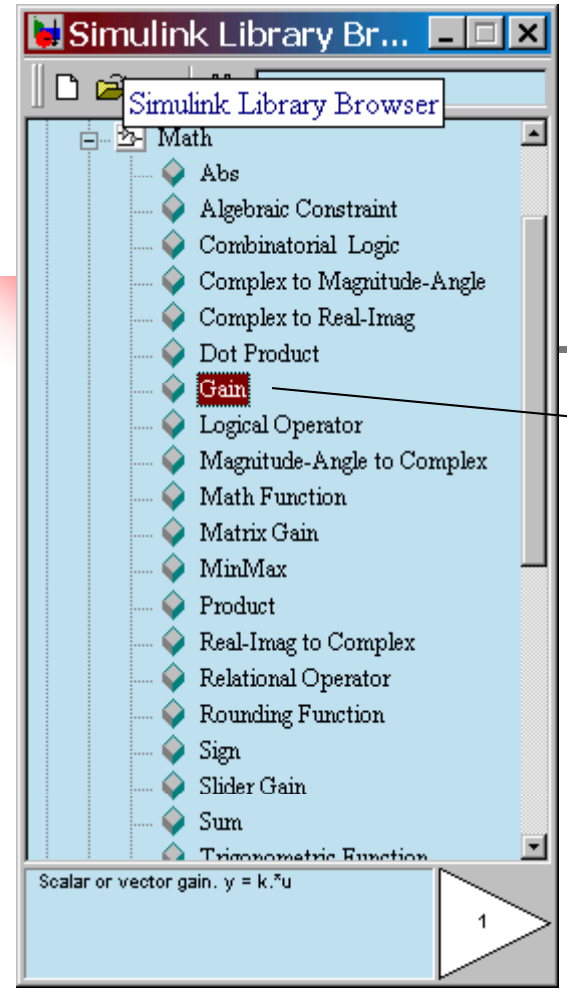
Drag a *Sum* block from the *Math* library

Double-click to change the block parameters to *rectangular* and *+ - -*

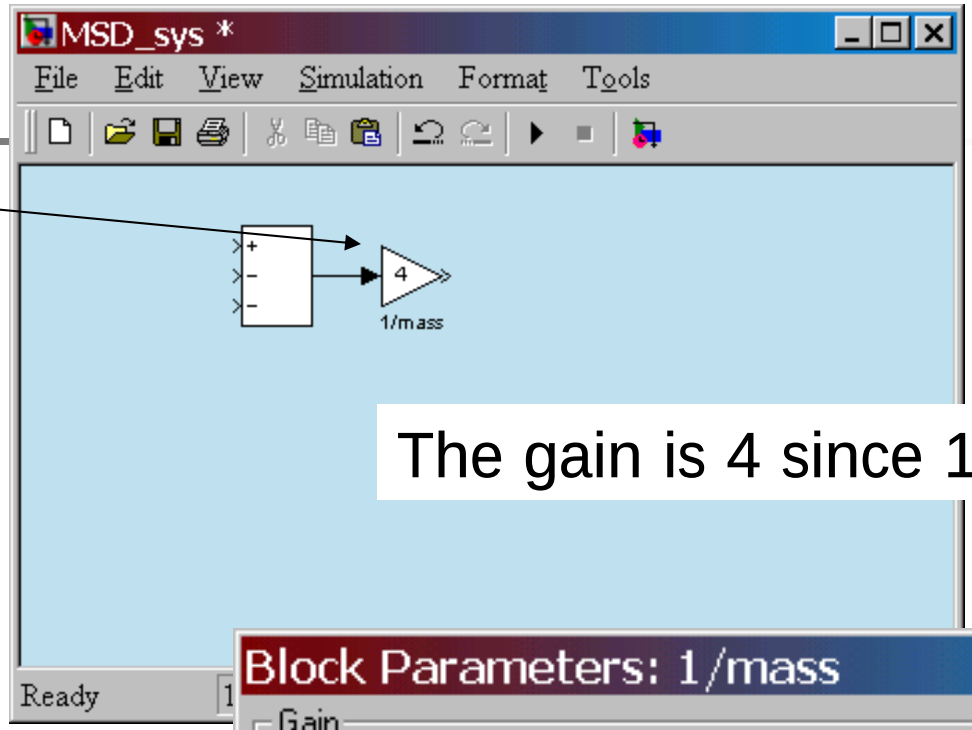
(continue)

- Add a gain (multiplier) block to eliminate the coefficient and produce the highest-derivative alone



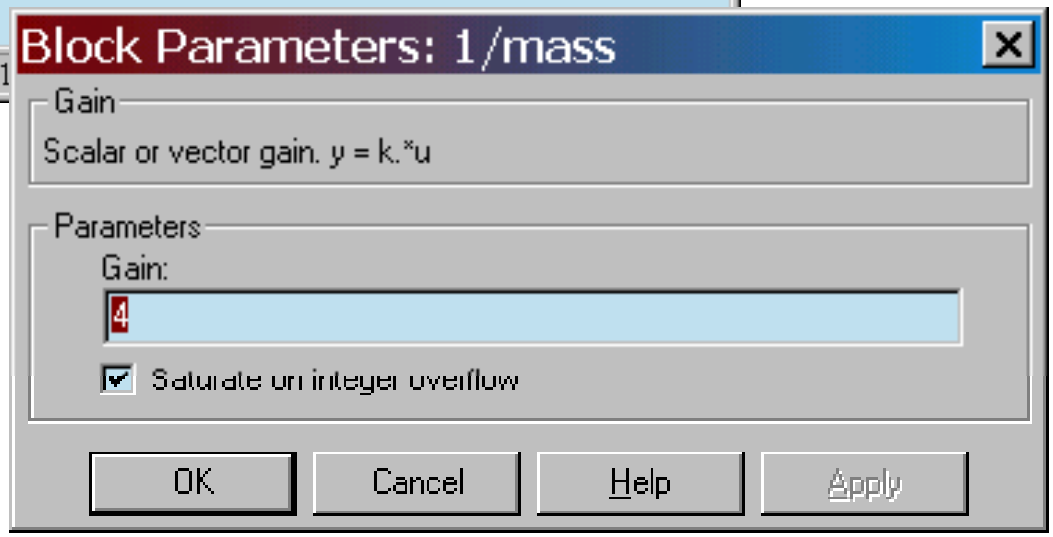


Drag a *Gain* block from the *Math* library



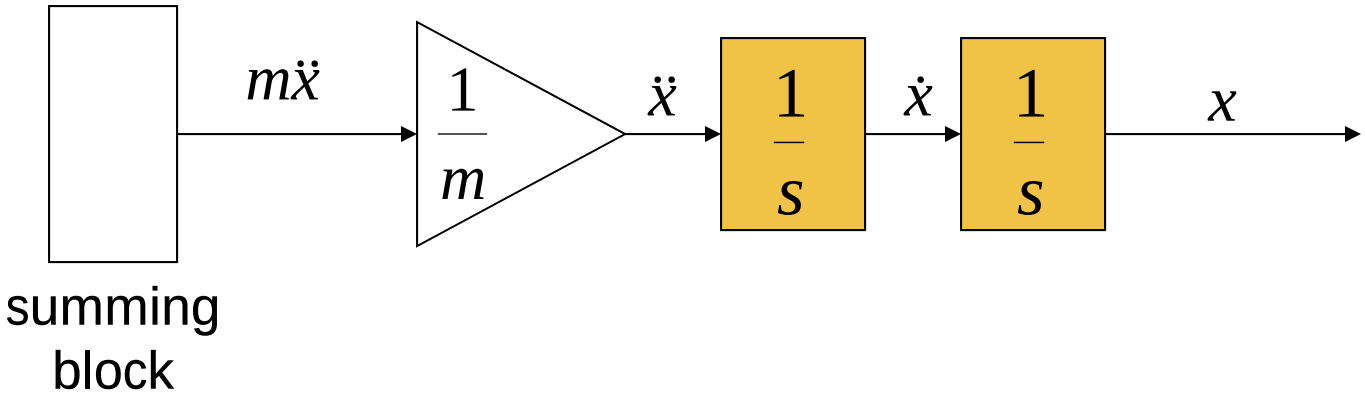
The gain is 4 since 1/m=4.

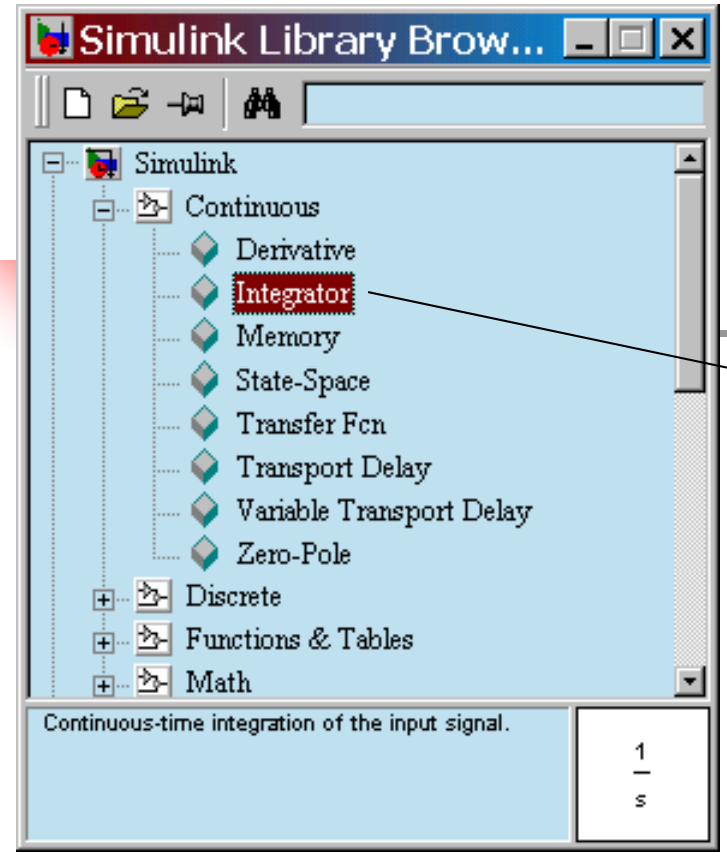
Double-click to change the block parameters.
Add a title.



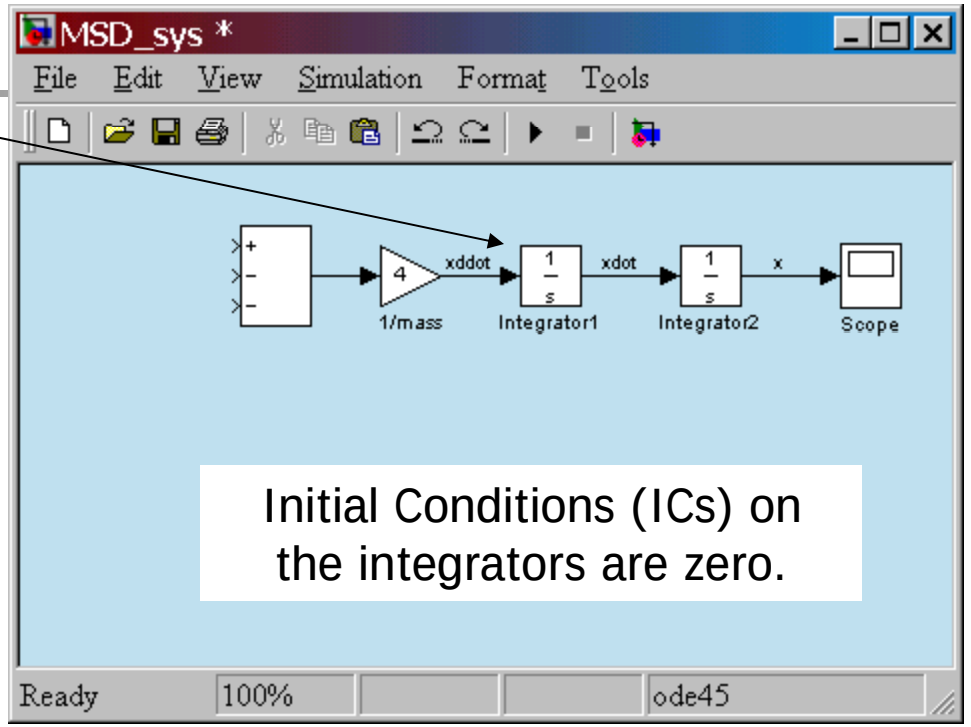
(continue)

- Add integrators to obtain the desired output variable





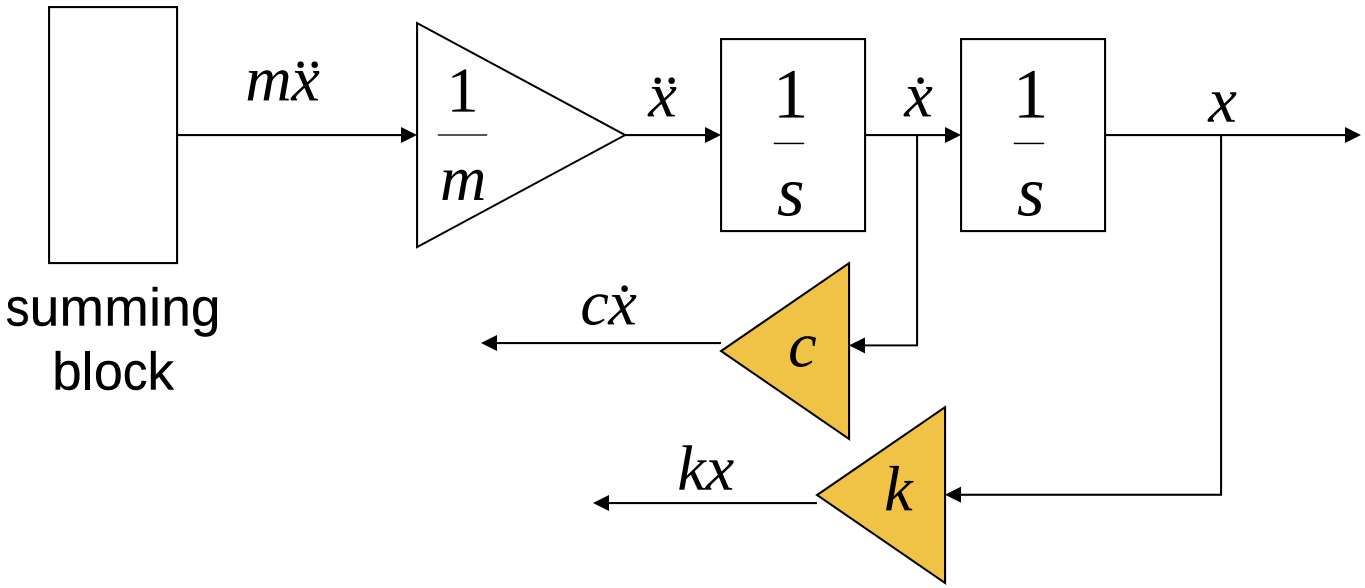
Drag *Integrator* blocks from the *Continuous* library

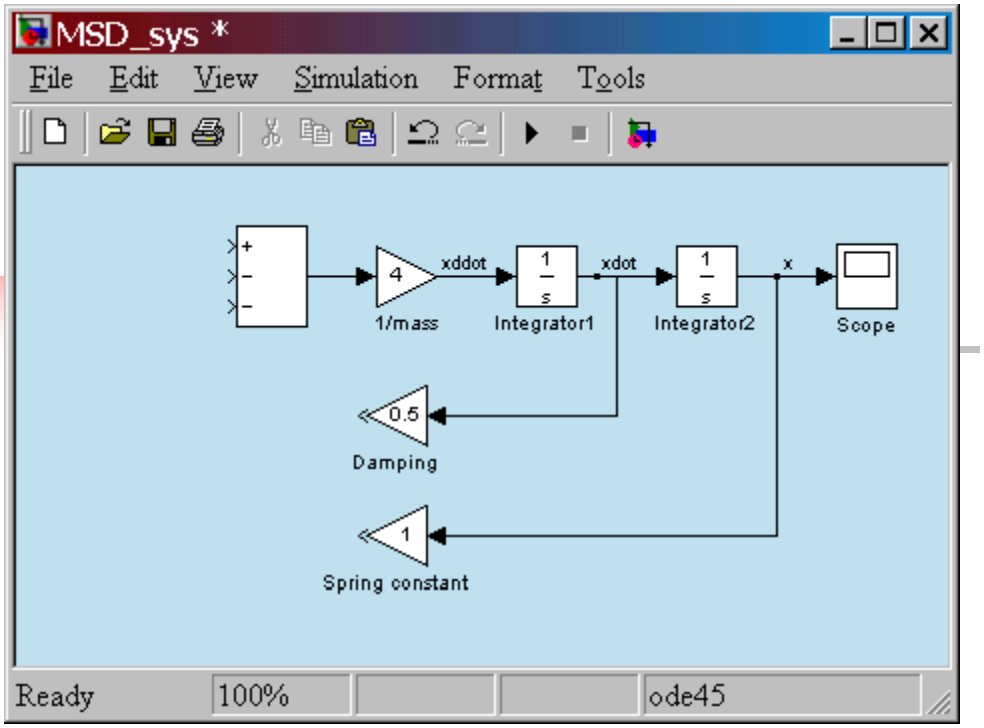


Add a scope from the *Sinks* library.
Connect output ports to input ports.
Label the signals by double-clicking on the leader line.

(continue)

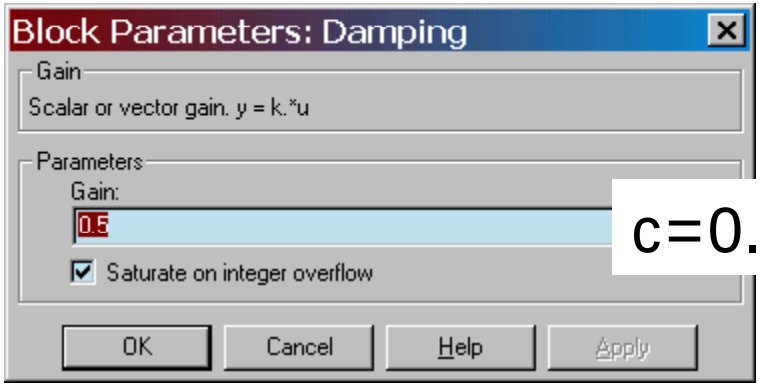
- Connect to the integrated signals with gain blocks to create the terms on the right-hand side of the EOM



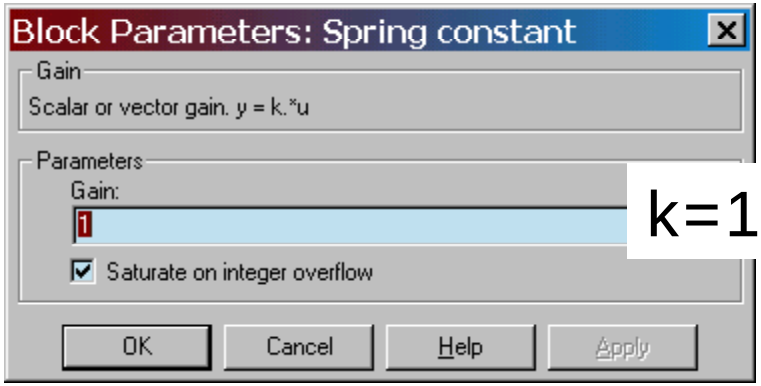


Drag new *Gain* blocks from the *Math* library

To flip the gain block, select it and choose *Flip Block* in the *Format* pull-down menu.



c=0.5

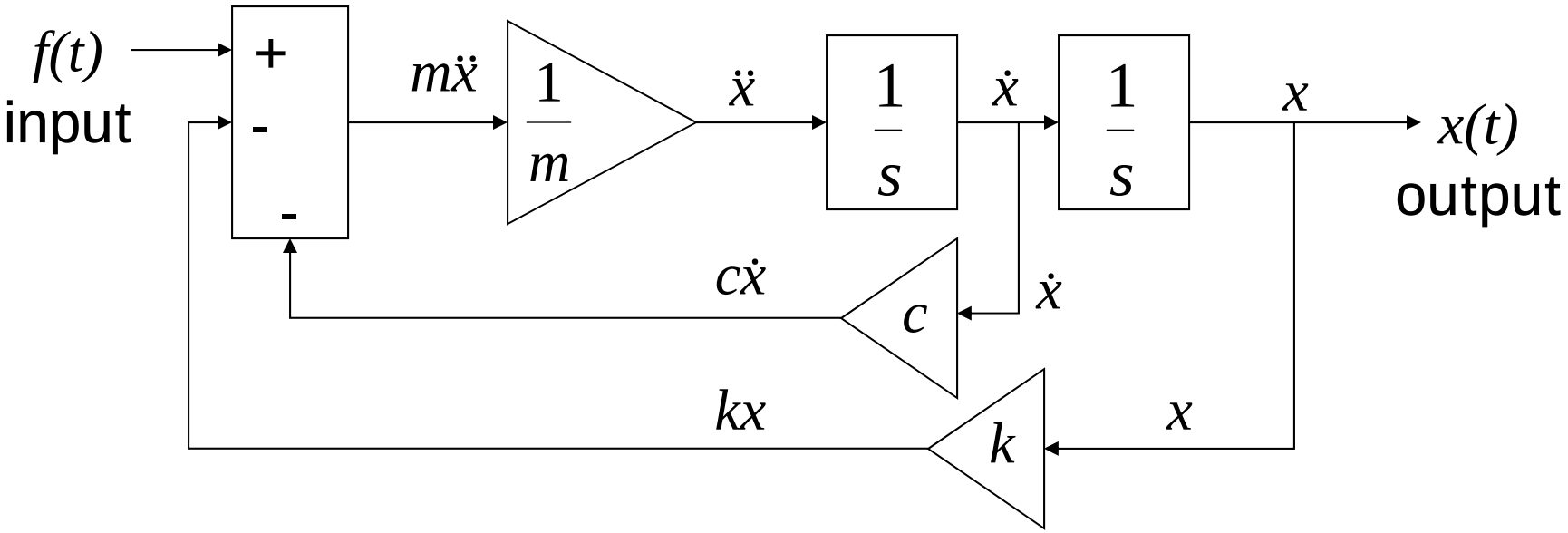


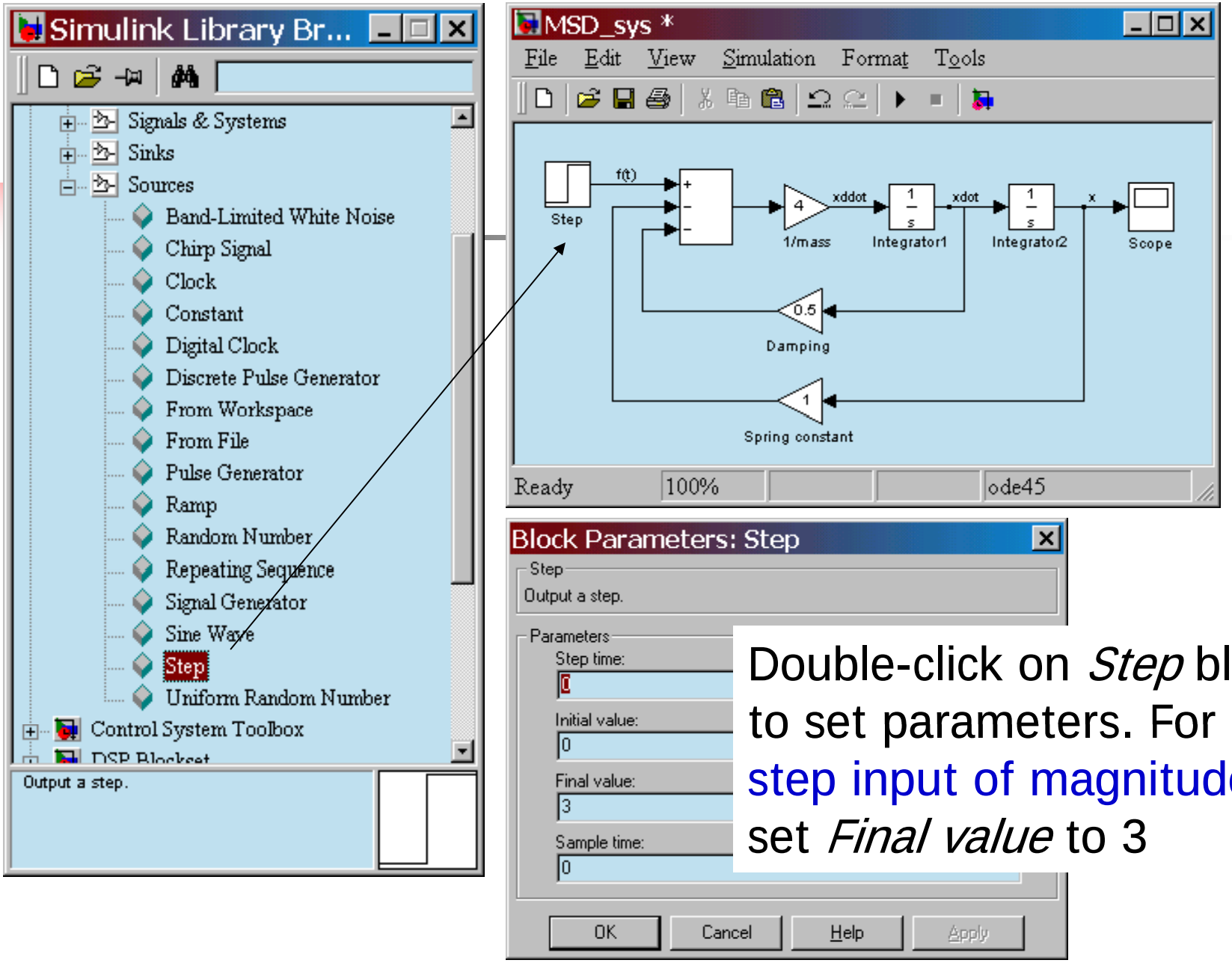
k=1.0

- Double-click on gain blocks to set parameters
- Connect from the gain block input backwards up to the branch point.
- Re-title the gain blocks.

Complete the model

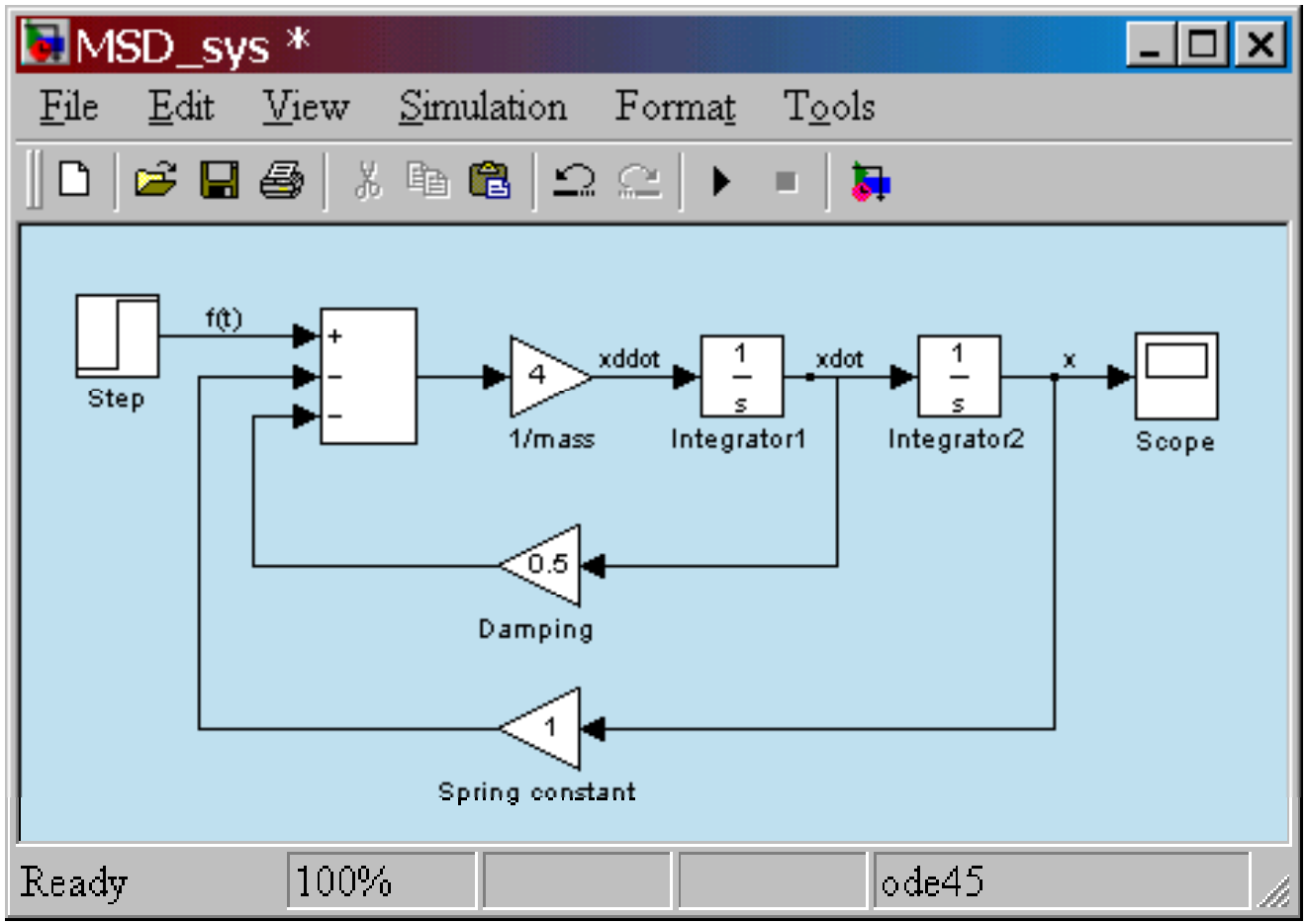
- Bring all the signals and inputs to the summing block.
- Check signs on the summer.



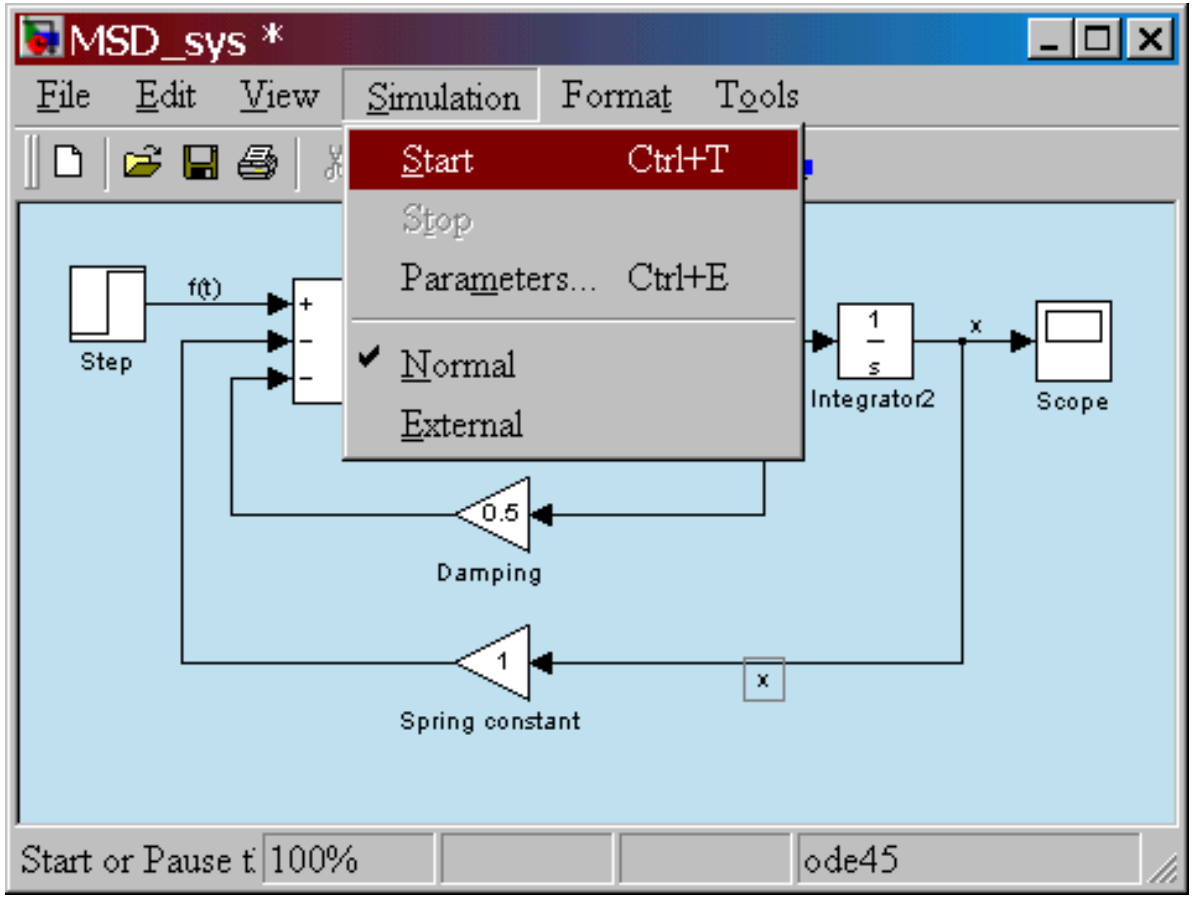


Double-click on *Step* block to set parameters. For a step input of magnitude 3, set *Final value* to 3

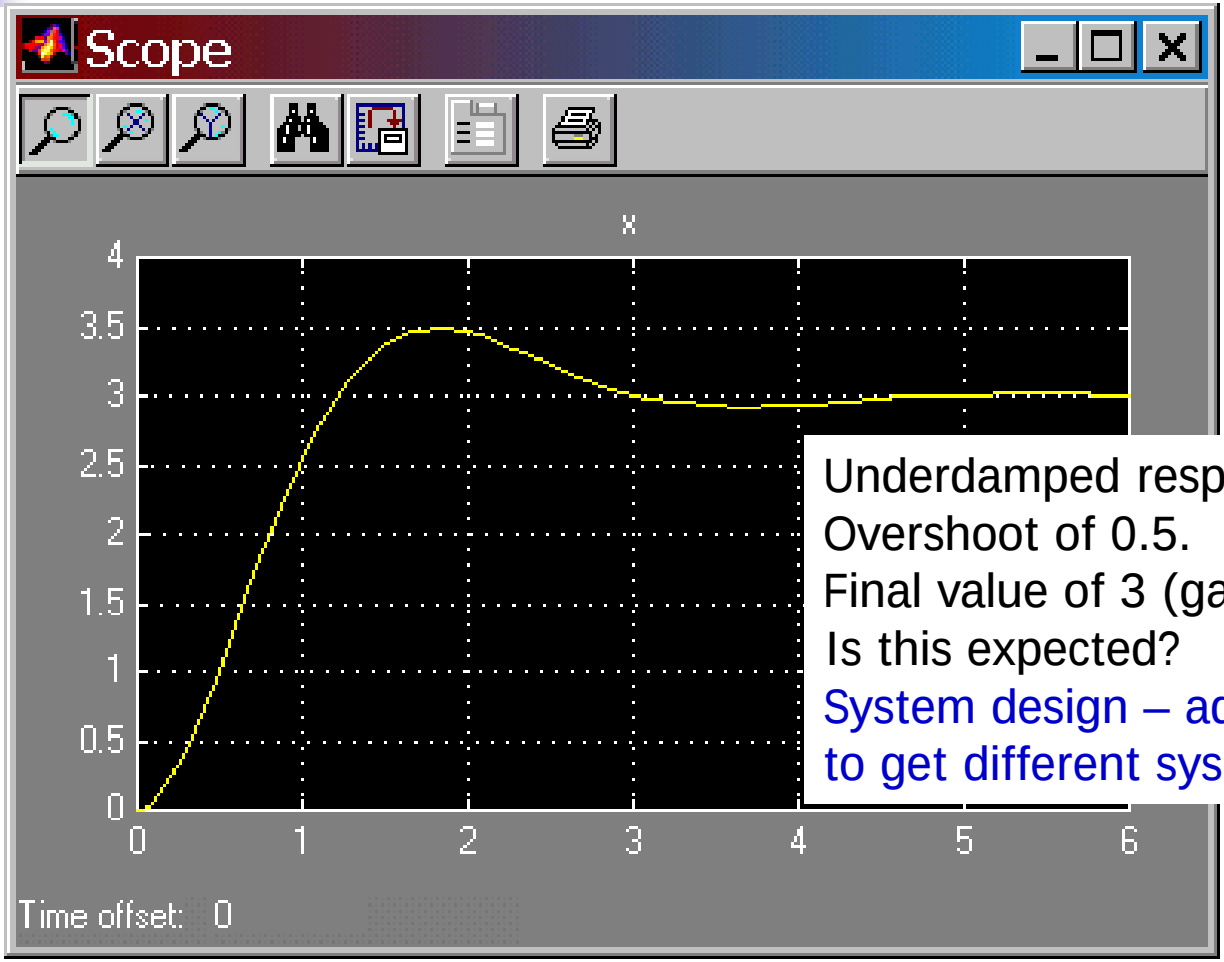
Final Simulink model



Run the simulation



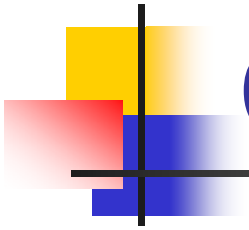
Results



Underdamped response.
Overshoot of 0.5.
Final value of 3 (gain = 1).
Is this expected?
System design – adjust *m, c, k* values to get different system response

Paper-and-pencil analysis based on the equations of motion

- Standard form $\frac{\ddot{x}}{k/m} + \frac{c}{k}\dot{x} + x = \frac{1}{k} f(t)$
- Nat'l freq. $\omega_n = \sqrt{\frac{k}{m}} = 2.0$
- Damping ratio $\frac{2\zeta}{\omega_n} = \frac{c}{k} \rightarrow \zeta = 0.5$
- Static gain $K = \frac{1}{k} = 1$



Check simulation results

- Damping ratio of 0.5 is less than 1.
  - Expect the system to be underdamped.
  - Expect to see overshoot.
- Static gain is 1.
  - Expect output magnitude to equal input magnitude.
  - Input has magnitude 3, so does output.
- Simulation results conform to expectations.